

Building Resilience through the Art of Maneuver or Architectures for Polycentric Governance

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C/S/E/L :2011

Prologue

“Even if the world were perfect, it wouldn’t be.”
Yogi Berra

Anomalies are what happens when something else was planned
whatever the plan, something else always happens.

- NASA circa 1999-2003
- Images of Resilience and Brittleness
- Plan for session

Fundamentals of complex adaptive systems drive systems.

Can resilience be engineered?

Tradeoffs circa 2000

- ~ optimality - brittleness tradeoff (Doyle)
- ~ acute-chronic
- ~ efficiency-thoroughness (Hollnagel)

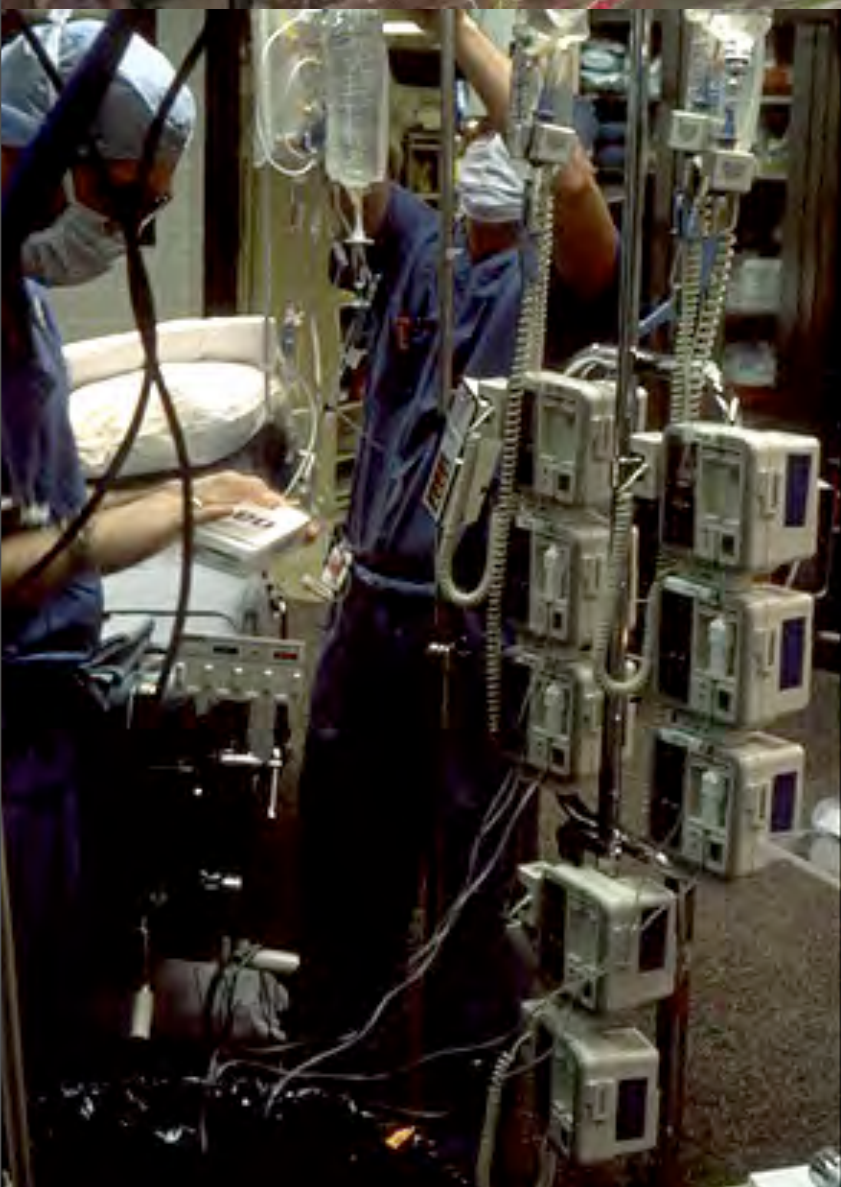
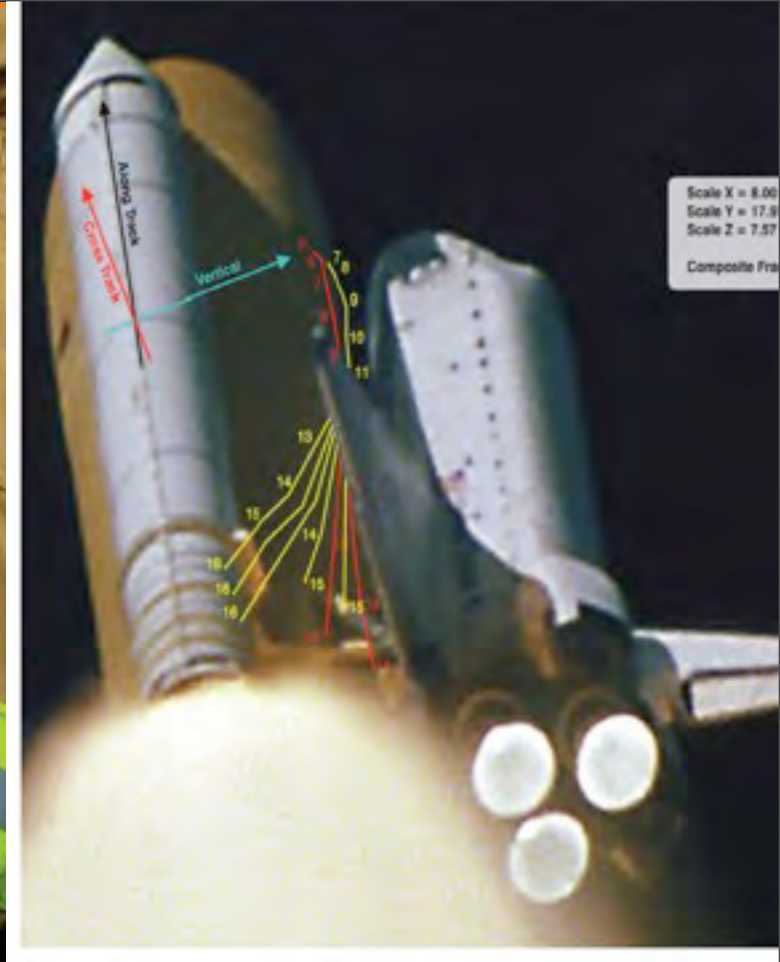
Patterns in being **Maladaptive**

Anticipation of shortfalls - regulate **Margin of Maneuver**

Fitness Spaces and graceful degradation - **Stress/Strain**

Polycentric Governance as a direction for Resilient Control Architectures

Walls of Complexity



“Systems”

Running into Walls of Complexity:

cumulative, creeping, inadvertent, due partly to successes

~ increasingly brittle systems

~ surprising failures

Fundamentals of Complex Adaptive Systems

~ new tools to model and measure the adaptive capacity of human systems

Resilience Engineering

~ provides ways to enhance resilience in face of surprise

~ predict how change expands or constricts adaptive capacities

~ new ways for managing interdependencies at scale

Complex Adaptive Systems under Faster, Better Cheaper Pressure

NASA failure history: cumulative complexity circa 2000



Creating Safety Under Pressure



NASA in a changing environment under performance demands and resource pressures:

- Drive down the cost of launch
- Shorter, aggressive mission schedules
- New partners and relationships
- New roles
- Skill erosion
- Heightened public interest

“Risk, therefore, becomes the “fourth dimension” of project management—treated equally as important as cost and schedule.”

NASA failure history captures cumulative complexity circa 2000



Design for Safety The Challenge



- Safety is a System Property
 - *Components, subsystems, software, interactions, organizations, human behavior*
 - *Continuous throughout the entire life-cycle*
- Traditional Methods do not address complex system issues
 - *System de-coupled => only components and subsystems addressed*
 - *Static, rule-based, deterministic process*
 - *Risk not explicit in trade space: entirely external to the main processes*
 - *Knowledge resides in people*
- Today's Challenge
 - *Increased mission complexity to meet ambitious goals*
 - *Increased resource constraints*
 - *Increased expectations: the safety bar raises every year*

NASA failure history captures creeping complexity

1999: 3 space exploration failures

2003: Run up to Columbia accident

Report on Project Management in NASA

by the
*Mars Climate Orbiter
Mishap Investigation Board*

March 13, 2000

increasingly brittle systems
under
faster, *better*, cheaper (FBC)
pressure



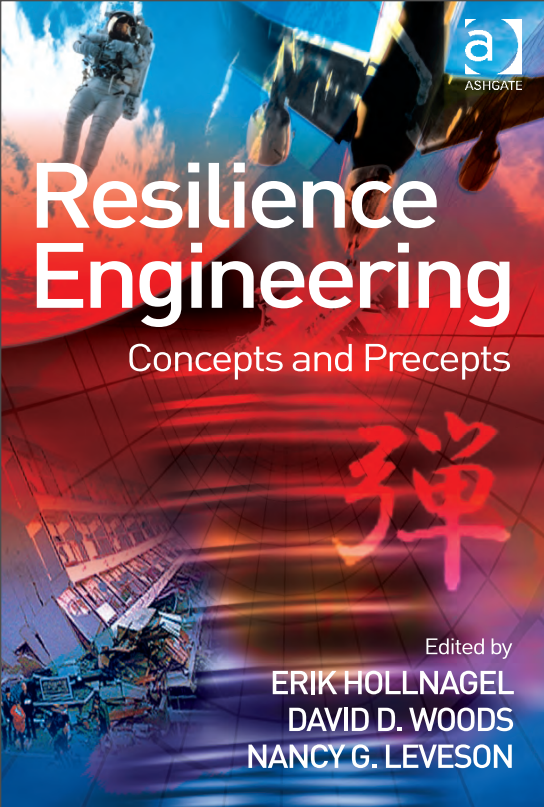
STS-112/ET-115 Bipod

• Rationale for Flight

- Current bipod ramp closeout has not been
- The Orbiter has not yet experienced "S of Flight" damage from loss of foam in 112 flights (including 3 known flights with bipod ramp foam loss)
- There have been no design / process / equipment changes over the last 60 ETs (flights)
- All ramp closeout work (including ET-115 and ET-116) was performed by experienced practitioners (all over 20 years experience each)
- Ramp foam application involves craftsmanship in the use of validated application processes
- No change in Inspection / Process control / Post application handling, etc
- Probability of loss of ramp TPS is no higher/no lower than previous flights
- *The ET is safe to fly with no new concerns (and no added risk)*



Bipod Attach Fitting



Complex Adaptive Systems / Resilience Engineering

- new sciences (measures, models, findings) on how adaptive system work and breakdown
- new techniques to
 - ~ enhance resilience in face of potential surprise
 - ~ monitor for increasingly brittle systems
 - ~ assess how change expands or constricts adaptive capacities



Images of Resilience, of Brittleness

Global Hawk UAV, 98-2003, 19991206, FSPM 1201A



through an aggressive and innovative programme of cost cutting on its P36 production facility.



SENSOR DAMAGE

The Law of Stretched Systems:
every system is continuously stretched to operate at its capacity.

People as problem holders exploit ‘improvements’ to better achieve goals by pushing the system out to operate near the edge of its new capacity boundaries. The process of adapting to exploit the improvement results in a new intensity, complexity, and tempo of activity.

| C/S/E/L | 1 | 2 | 3 | 4 | Patterns in Cognitive Work |
|---|-----|-----|-----|-----|----------------------------|
| | 1.1 | 1.2 | 1.3 | 1.4 | |
| Patterns of Reverberations | | | | | |
| <p>Much of the equipment deployed ... was designed to ease the burden on the operator, reduce fatigue, and simplify the tasks involved in operations. Instead, these advances were used to demand more from the operator. Almost without exception, technology did not meet the goal of unencumbering the personnel operating the equipment</p> <p>... systems often required exceptional human expertise, commitment, and endurance.</p> <p>... there is a natural synergy between tactics, technology, and human factors ... effective leaders will exploit every new advance to the limit. As a result, virtually every advance in ergonomics was exploited to ask personnel to do more, do it faster and do it in more complex ways.</p> <p>... one very real lesson is that new tactics and technology simply result in altering the pattern of human stress to achieve a new intensity and tempo of operations.</p> | | | | | |

Sample 1: Resilience

Shortly before surgery, an attending anaesthesiologist comes to understand that the surgical plan expects a relatively short procedure with little blood loss. However, the attending recognizes that given this patient's other problems, it will be difficult to establish access quickly if significant fluid replacement is needed to manage cardiovascular physiology. Furthermore, the anaesthesiologist recognizes that, while the surgical plan represents a typical surgical course, in this context the procedure could go much longer and blood loss could be much greater than expected. As a result, the attending instructs the resident to place more lines than normal when the patient is being prepped for surgery. This will allow the attending to respond quickly with fluid replacement should any challenges to cardiovascular physiology occur during surgery.

Sample 2: Resilience

Anesthesiology has become much safer over the last 15 years. In addition, there have been changes in medical practice that allow for/encourage surgeries to occur in outpatient settings (e.g., cosmetic surgery). As a result, anaesthesia practice has migrated away from the traditional operating room setting where there are a variety of technological and human resources that can be called on should a crisis occur. The safety manager for the health care network recognizes that moving more anaesthesia practice to outpatient settings increases brittleness, that is, should an unexpected event trigger a crisis, less expertise, experience, and equipment is available to manage the situation. The safety manager initiates a new crisis management training program for outpatient surgery teams that allows personnel to practice how to respond to a crisis including how to find and bring additional expert resources into the different locations where a crisis could occur.

easy to see a person or a piece of technology
easy to see components, rules
easy to see things

hard to see expertise

harder to see interactions, coordination, synchronization

harder yet to see adaptation, complexity, brittleness,
resilience

easy to mistakenly—

juxtapose people versus machines,

see erratic human behavior,

regulate components

when the *dynamics of complex adaptive systems* are the
underlying drivers

A. Adaptive capacity exists before disrupting events call upon that capacity
(it is a potential for future adaptive action)

B. One assesses (observes/models/measures) adaptive capacity through its exercise in the anticipation and reaction to past disruptions.

(A) means that the resources that support the potential, prior to visible disrupting events, may not be seen at all since they are not used; or if seen, they will be seen as excess capacity since it is not in use.

Under FBC pressures, systems tend to lose Margins of Maneuver

Monitor/Regulate **Margin of Maneuver**

Fundamentals of complex adaptive systems drive systems

- **Fundamental Tradeoffs:**
unification for human adaptive systems
- 3 basic ways systems can be **Maladapted**
- **Regulate Margin of Maneuver:**
maintain ability to handle the next event
- **Stress/Strain Fitness Space:**
representing how systems stretch to handle surprise
- **Polycentric Governance**
regulating interactions across centers of adaptive behavior (CABs)

Adaptive Histories

are you collecting, sharing, analyzing stories of resilience and brittleness?

Precarious Present

tendency to be mis-calibrated and overconfident

Resilient Future?

how do/will changes effect sources of resilience and points of brittleness?

If I could go back to NASA's Design for Safety meetings, my answer to the question what is the fourth parameter?

Monitor/Regulate Margin of Maneuver

1. Fundamentals of Complex Adaptive Systems in a Faster, Better, Cheaper World

Unification of Fundamental **Tradeoffs**

David Woods

to see “very well that it was necessary to perish in order not to perish; and to expose oneself to dangers of all kinds, in order to avoid all dangers.

Jesuit Relations (1656-57)

- Optimality-Brittleness
Gaps in Fitness / Bounded Ecology
- Efficiency-Thoroughness
Gaps in Plans / Bounded Rationality
- Distant-Local
Gaps in Perspectives / Bounded Perspicuity
- Acute-Chronic
Gaps across Roles / Bounded Responsibility
- Concentrated-Distributed
Gaps in Progress / Bounded Effectivity

5 Bounds

Bounded Ecology

an adaptive system can never match its environment completely;
the struggle for fitness is ongoing
though it eases & intensifies with change

Gaps in Fitness

trigger surprises

impetus for resilience

‘Extra’ capacity to adapt to cope with surprise
to re-balance the trade-off between optimality & brittleness
(RYF - robust yet fragile)

5 Bounds

Bounded Cognizance

algorithms, embodied in any form, operate with finite resources and thus are fallible; limits in deploying knowledge to effect.

Gaps in Plans

trigger surprises

impetus for learning

Adapting plans to fit the situations actually at hand
to re-balance the trade-off between efficiency & thoroughness
(ETTO)

5 Bounds

Bounded Perspicuity

The view from any point of observation simultaneously reveals and obscures. This limits an adaptive system's ability to see and assess the world around them

Gaps in Perspective

trigger surprises

invitation for reflection

Shift and Contrast Perspectives
to re-balance the trade-off between Local & Distant
(Sharp End / Blunt End; In-scene / Out-of-scene)

5 Bounds

Bounded Responsibility

all systems pursue multiple goals that interact and can conflict; responsibility and risks associated with achieving or failing to achieve goals are divided over roles at different levels or echelons of a system

Gaps across Roles

trigger surprises

invitation to coordinate

Adjust forms of coordination
to re-balance the trade-off between acute & chronic
(sacrifice judgments)

5 Bounds

Bounded Effectivity

adaptive systems are restricted in how they can act on the world and influence processes underway. No single controller is omnipotent.

Gaps in Progress

trigger surprises

impetus for fluency

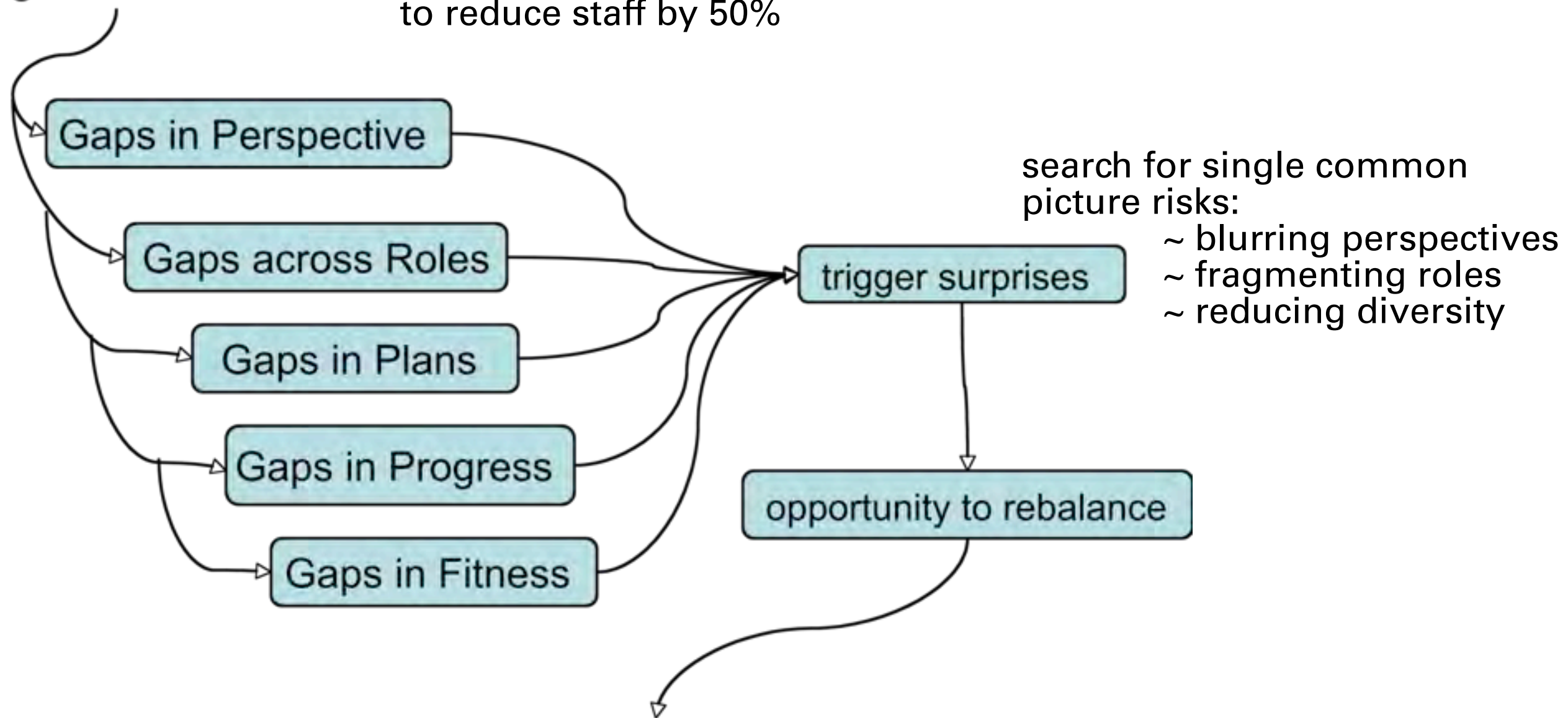
Adapting authority and initiative across multiple centers to re-balance the trade-off between concentrated & distributed (polycentric governance)

Unification of Fundamental Tradeoffs?

- Hard limits
- No free lunch-NFL (or conservation laws?)
- Human adaptive systems: intentional and reflective
 - ~ generally far from hard limits - precarious
 - ~ miscalibrated and overconfident
- Interventions produce unintended consequences

CASE 1: use advances in autonomy
to fuse data into a common operating picture with a
new interface
to reduce staff by 50%

Change and variation



- provide multi-perspective displays that contrast and connect different perspectives via means to
 - ~ explore across perspectives
 - ~ share perspectives across roles
 - ~ shift fluently between outside in and inside out views
 - ~ control of point of view
- expand diversity of conceptual perspectives
- synchronize which perspectives are relevant when

Mis-Calibration

organization is operating more precariously than it realizes

Organizations generally

- ~ mis-estimate their adaptive capacity (level and kinds)
- ~ overconfident that they know it precisely

Resilient Organizations

- ~ acknowledge uncertainties and change
- ~ struggle to update and re-calibrate
- ~ support sacrifice judgments—contexts to relax acute goals to serve chronic goals

Fundamental Tradeoffs and Key Challenges

- Monitor system's position in trade space [when you are in the system]
 - (a) the problem of discriminating inefficiencies from sources of resilience
 - (b) the problem of estimating whether a system is becoming increasingly brittle over time.
- Regulate system's position in trade space [when you are in the system] -- architectures for evolvability or resilient control
 - ~ regulate Margin of Maneuver
 - ~ Polycentric Governance

2. How Adaptive Systems Fail: Three patterns of maladaptive behavior across scales

David Woods

- Potential for Surprise
- Three patterns in being maladapted
 - ~ Decomensation
 - ~ Working at cross-purposes
 - ~ Getting stuck in outdated behaviors
- Anticipation of shortfalls - regulate Margin of Maneuver

A common expression from military decision making:
No plan survives contact with a disaster-in-the-making.

... our experience [is] that every response is totally different and causes unforeseen problems or opportunities. We have never gone to an actual response and used the equipment the way we thought we would. (Murphy & Burke, 2005, p. 4)

How to be Prepared to be Surprised?

Potential for surprise is related to

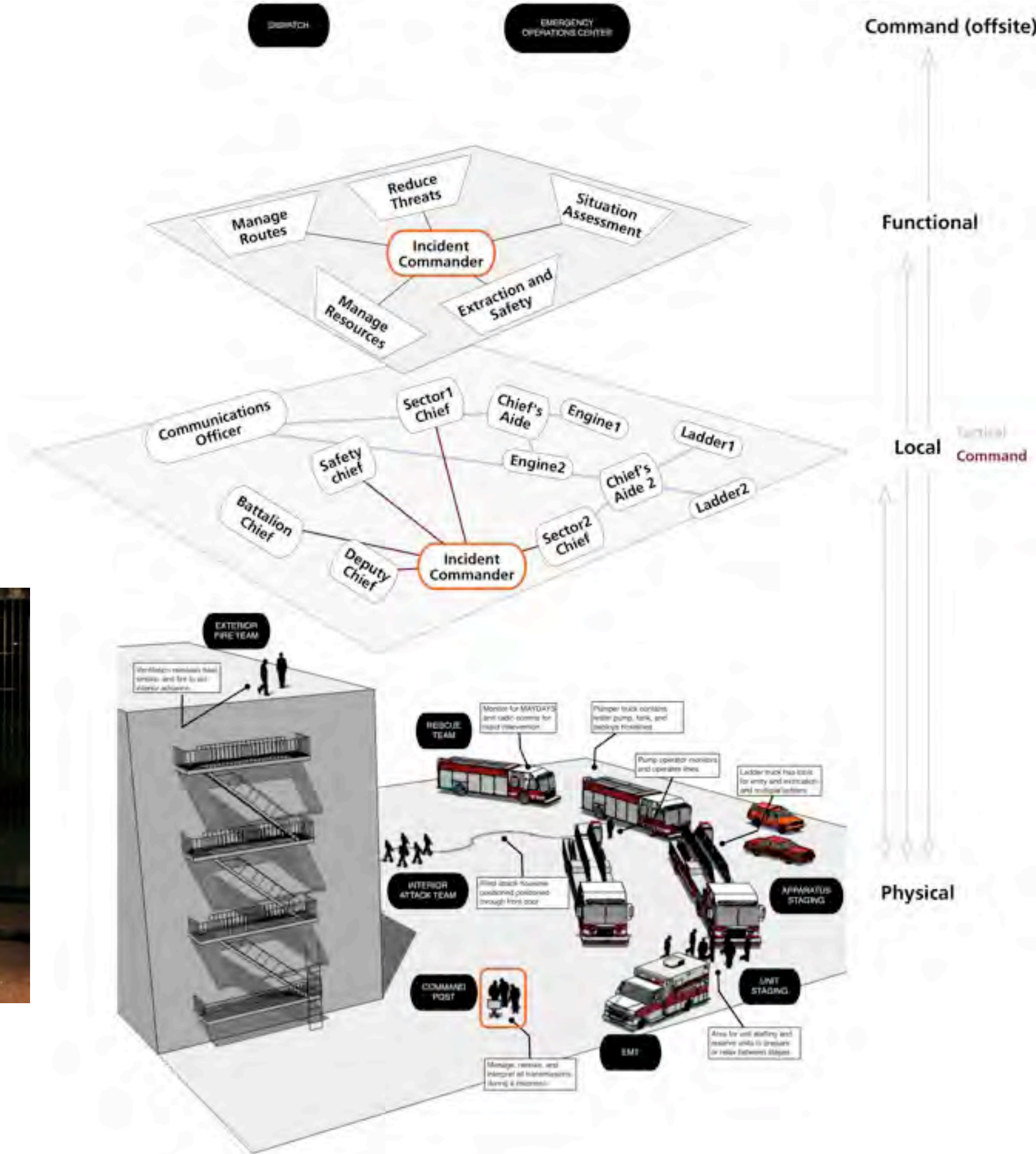
- the next anomaly or event that practitioners will experience and
- how that next event will challenge pre-developed plans and algorithms in smaller or larger ways.

To assess potential for surprise in a setting,
ask how the above generalization applies?

- *how do plans survive or fail to survive contact with events?*
- search for the kinds of situations and factors that challenge the textbook envelope

Urban Firefighting

- ~ distributed roles
- ~ multiple echelons
- ~ disrupting factors
- ~ multiple goals
- ~ interdependencies



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Maladaptive Patterns and Critical Incidents in Urban Firefighting (Branlat et al., 2009)

Decompensation

- If request resources when need is definitive, it is already too late
- Regulate additional adaptive capacity (tactical reserves)
 - ~ maintain **margins of maneuver** (ability to handle next surprise)
 - ~ “avoid all hands situations” (incident command)
- Bumpy transfers of control

Working at cross-purposes (both horizontal and vertical)

- Actions of one group increase threats to other groups (opposing fire hoses; rendering escape routes or protected areas inaccessible)
- Failure to resynchronize
- Goal priorities/conflicts in response to distressed firefighter
- Tradeoff between information sharing versus data bottlenecks

Getting stuck in outdated behaviors

- Failures to modify plan in progress as situation changes

Patterns of Adaptive Breakdown - Mal-Adapted

Complexities in time --> **Decompensation**: exhausting capacity to adapt as disturbances/challenges cascade.

breakdown occurs when challenges grow and cascade faster than responses can be decided on and deployed to effect.

Complexities over scales --> **Working at cross-purposes**: behavior that is locally adaptive, but globally maladaptive
inability to coordinate different groups at different echelons as goals conflict.

- Fragmentation (stuck in silos)
- Missing side effects of change (temporal)

Complexities in learning --> **Getting stuck** in outdated behaviors: the world changes but the system remains stuck in what were previously adaptive strategies.

- Oversimplifications
- Fixation

1. Decompensation

breakdown occurs when challenges grow and cascade faster than responses can be decided on and deployed to effect.

- ~ Starling curve cardiology
- ~ cardiovascular anesthesiology (Cook)
- ~ asymmetric lift, aviation automation, bumpy transfer of control (Sarter & Woods)
- ~ 'surge' capacity in ER (Wears)
- ~ ICU bed crunches (Cook)
- ~ Tempo of operations

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Box 1 Example of a case of "going solid"

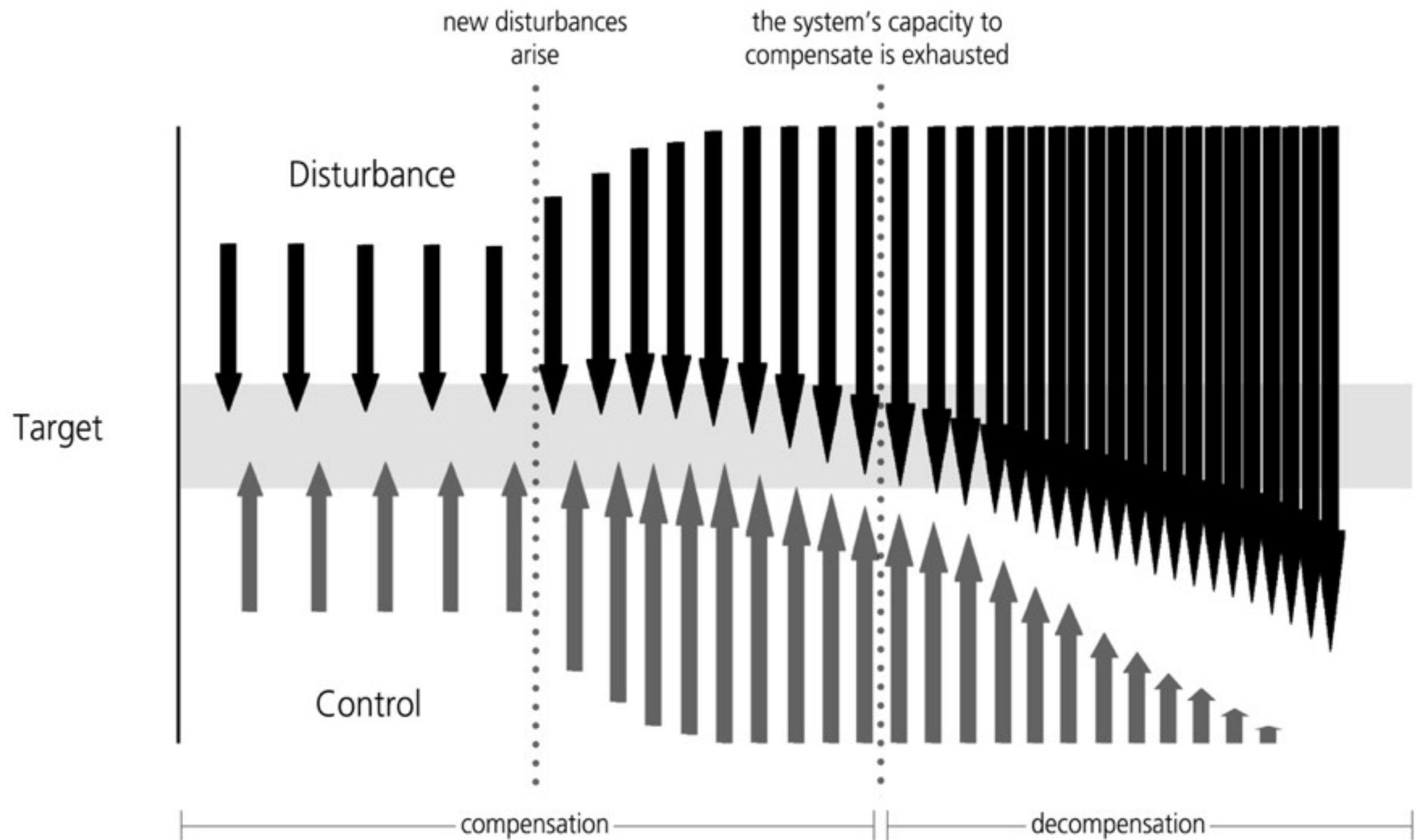
Setting

A large tertiary care facility in a major metropolitan area in the United States.

Event

Near the end of a routine scheduled surgical procedure on patient A, the circulating nurse called the recovery room in anticipation of bringing the patient to it. The recovery room placed the transfer from the operating room "on hold" because all the recovery room locations were filled by patients. Among these was patient B who should have been transferred from the operating room directly to an intensive care unit (ICU) bed. Patient B was in the recovery room because there was no ICU bed available. Investigation of the circumstances revealed that the ICU bed was occupied by patient C whose condition would allow transfer to the regular ward but the regular ward bed was occupied by patient D who was ready for discharge but was awaiting arrival of a family member to transport him to his home. Bed occupancy within the hospital had been at saturation for both ICU and regular ward beds for several weeks.

The high occupancy situation was managed by nurses and administrators by pairing new postoperative admissions with anticipated patient discharges, matching expected discharge and expected end of surgery times. Senior hospital management became involved in moment to moment decision making about bed allocation, surgical procedures starts, and intra-hospital patient transfers. Managers also sought increased efficiency of resource use, mainly through direct inquiries about patient status. A new administrative nursing position was established to centralize and rationalize bed resources. The system remained solid for approximately 5 weeks.



2. Working at cross-purposes: behavior that is locally adaptive, but globally maladaptive

~ inability to coordinate different groups at different echelons
as goals interact and could conflict.

sub-patterns (horizontal and vertical):

- Tragedy of the commons
- Fragmentation (stuck in silos).
- Missing side effects of change (temporal)
- Failure to resynchronize
- Double Binds

3. Getting stuck in outdated behaviors:
the world changes but the system remains stuck in what were
previously adaptive strategies.

sub-patterns range over temporal and organizational scales

- Oversimplifications
- Failing to revise current assessment as new evidence comes in (Fixation)
- Failing to revise plan in progress when disruptions/opportunities arise
- Discount discrepant evidence (e.g., run up to Columbia)
- Literal Mindedness (automation failures)
- Distancing through differencing
- Cook's Cycle of Error

Monitor/Regulate **Margin of Maneuver**:

Cushion of potential actions and additional resources that allows the system to continue functioning despite unexpected demands.

How much active control margin or capability is left to handle the next event or disturbance?

Each center of adaptive behavior works to create, maintain, and manage their margin of maneuver.

Locally adaptive as one center manages its margin relative to interdependencies with other centers' behaviors to manage their margin

Failure to maintain margin leaves the system too brittle and increases the risk of falling into the maladaptive traps (eg, locally adaptive, globally maladaptive)

Resilient systems are able to anticipate how margins of maneuver are expanding or contracting relative to the potential for surprise.

3. Adapting to Surprise

Stress-Strain Fitness Space

David Woods

Analyze how the unit has adapted to past disrupting events

Adaptive capacity is future oriented -- what and how the unit could stretch in the future.

A common expression from military decision making:
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Emergency Medicine

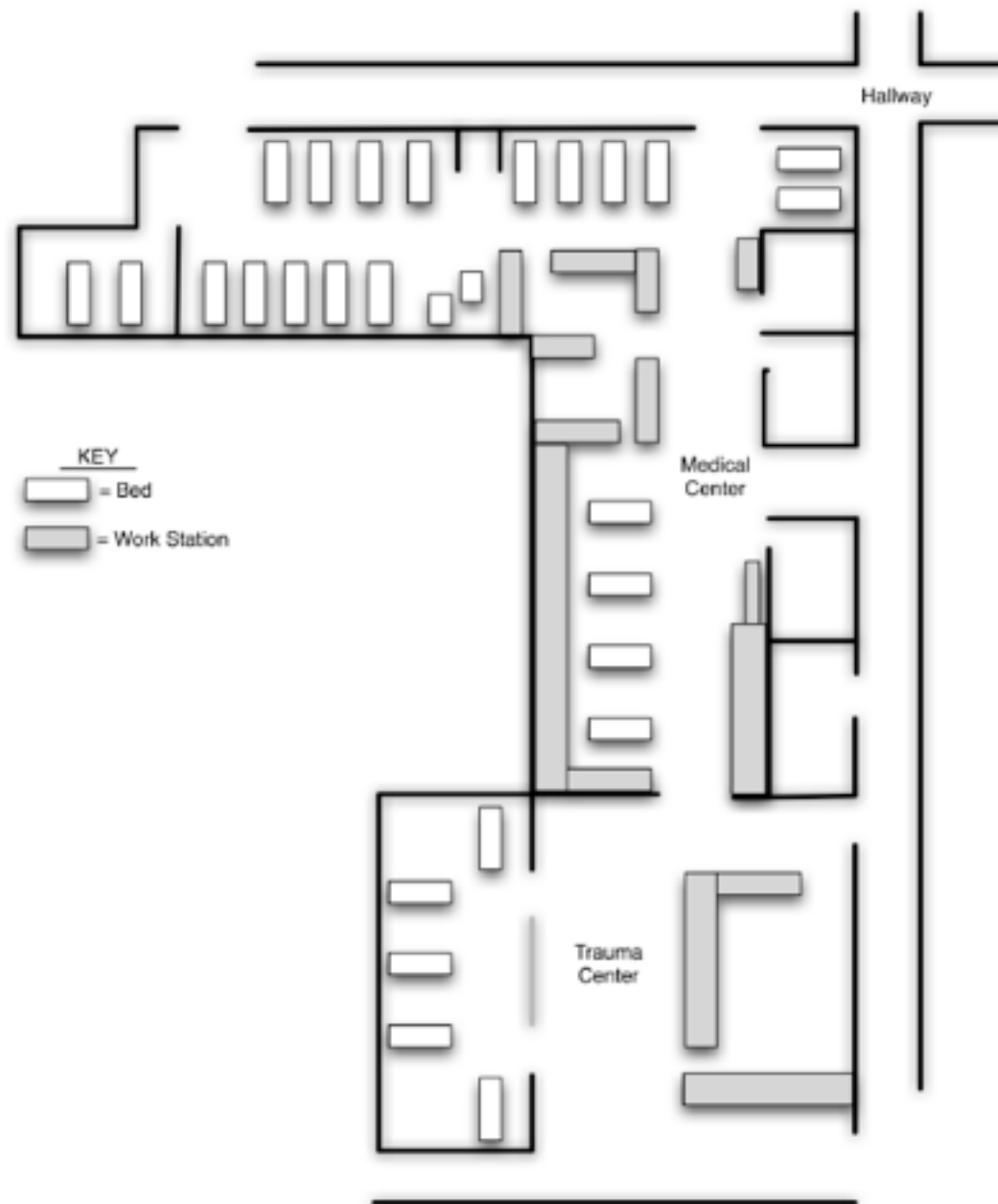
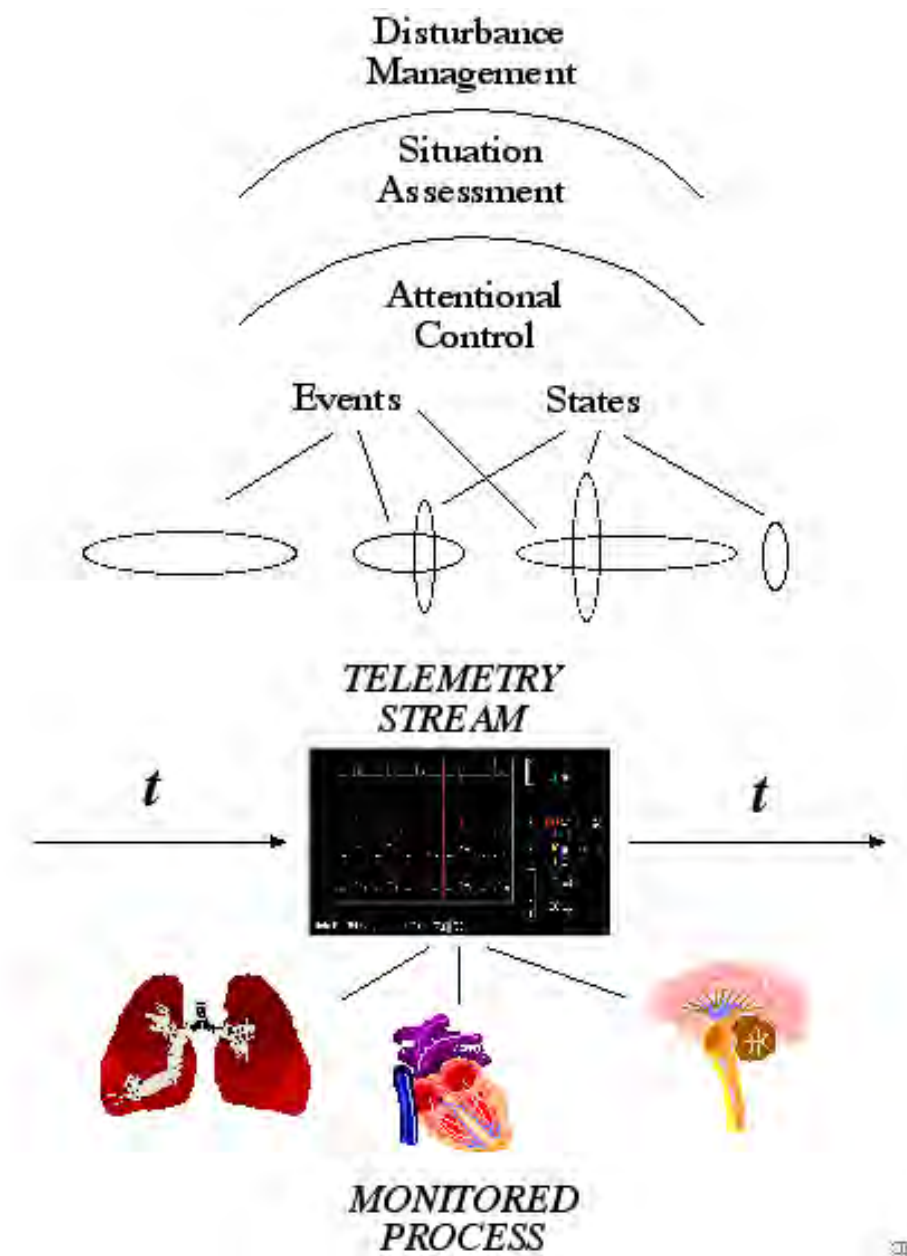
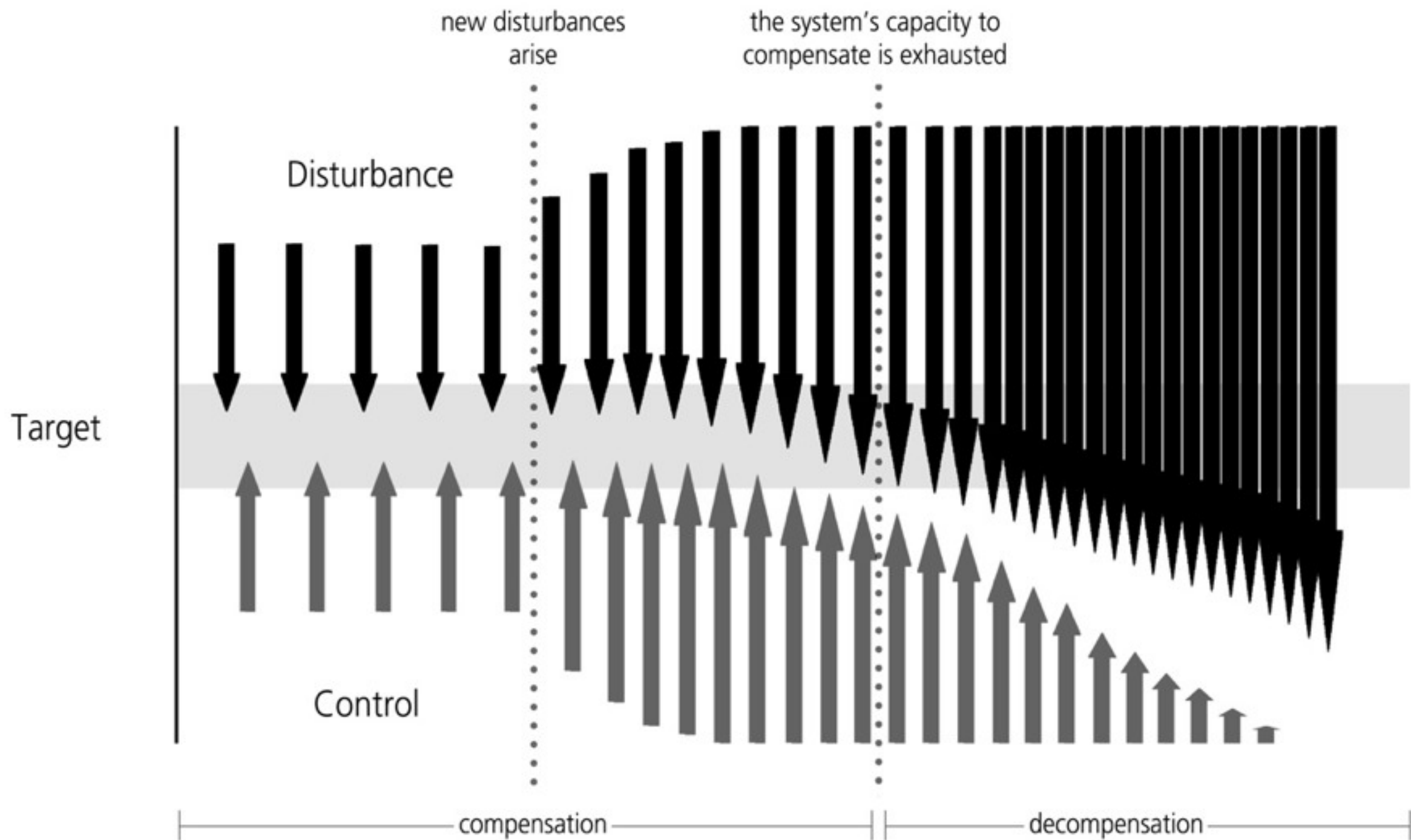
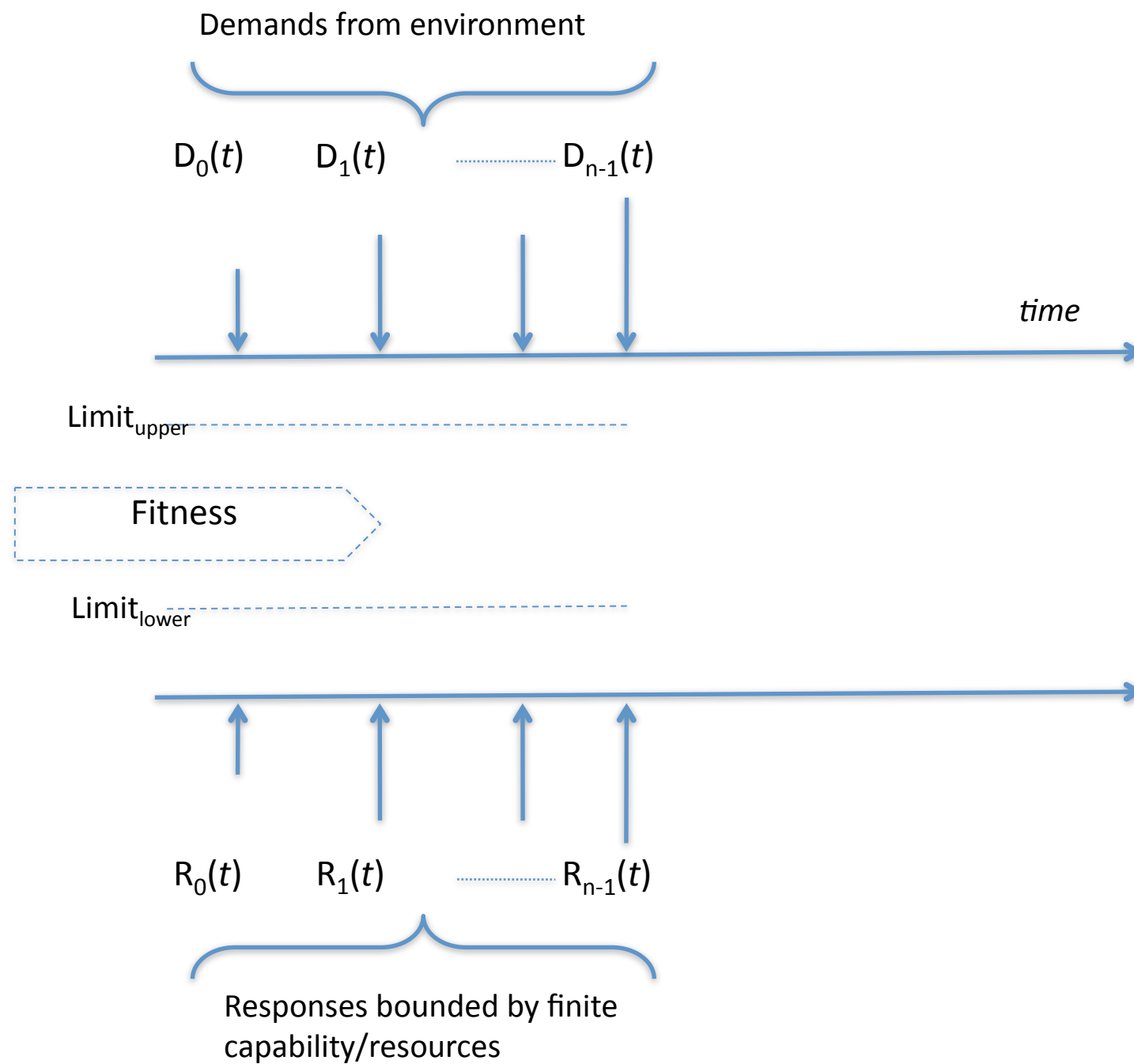
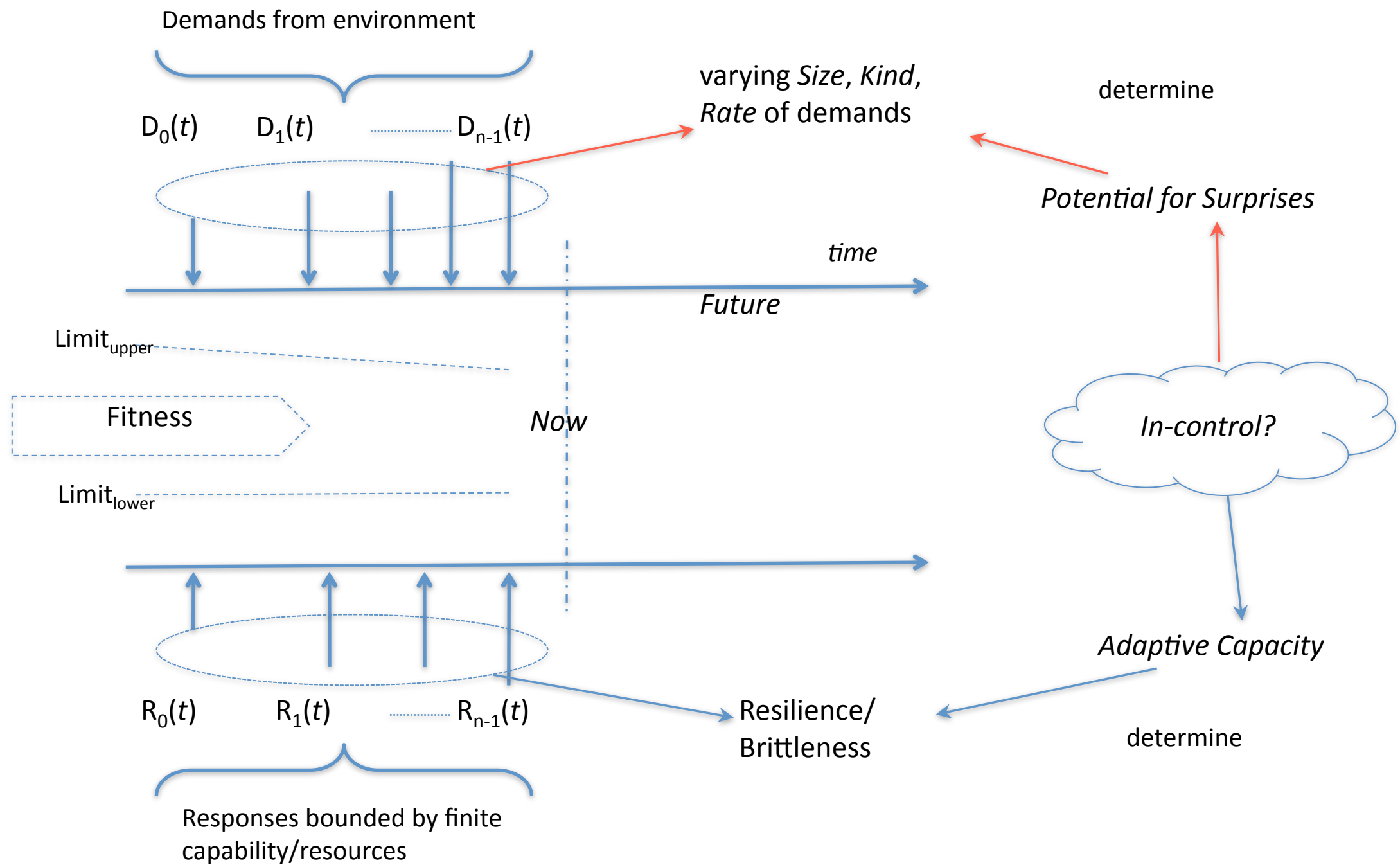


Figure 1. Schematic layout of the two units involved in these events.

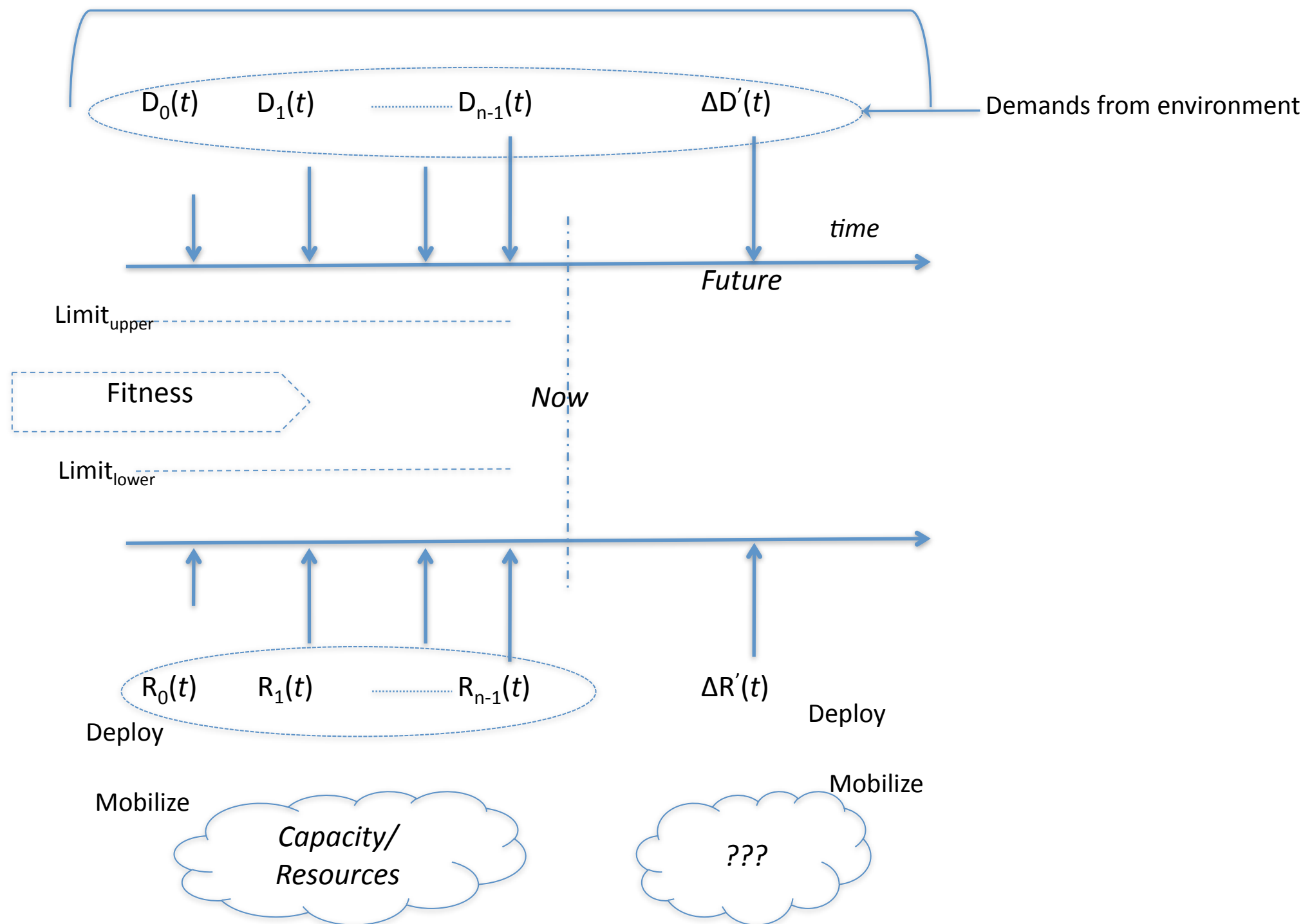


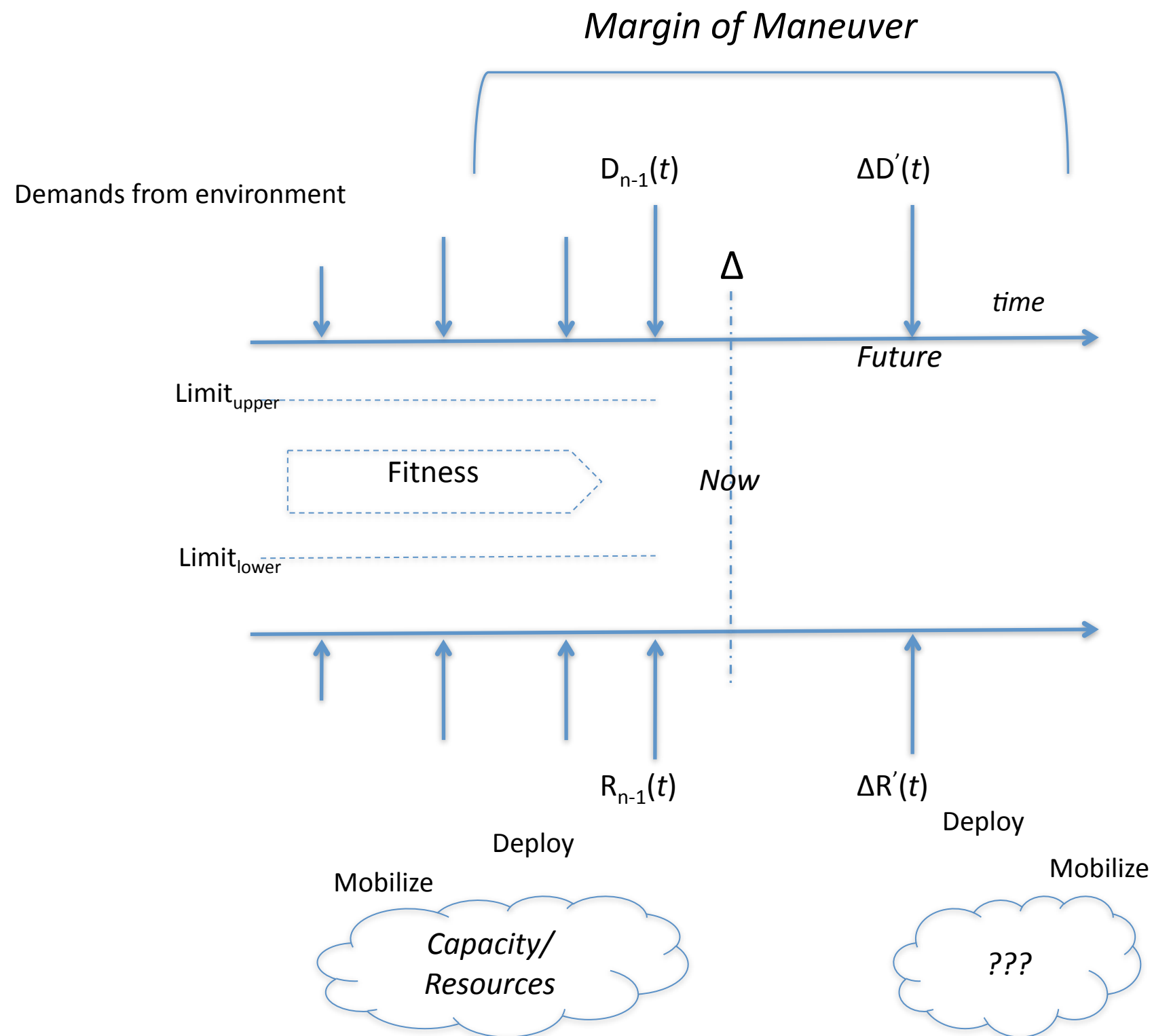






Margin of Maneuver





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**Demanding
Events**

**Demanding
Events**

**Demanding
Events**

150

The diagram consists of a large, light gray rectangular area. On the left side of this area is a vertical stack of eight thin, slightly curved rectangular bars of varying shades of gray, creating a 3D effect. To the right of these bars is a large, empty rectangular space. A solid black vertical line separates the bars from this space. Two horizontal dashed lines cross the entire diagram, one near the top and one near the bottom. In the bottom center of the diagram, there is a gray trapezoidal shape with a black outline, containing the text 'Adaptive Responses'.

**Demanding
Events**

**Adaptive
Responses**

The diagram consists of three main components arranged in a triangle, connected by dashed lines. At the top left is a light gray rounded rectangle containing the text 'Demanding Events'. At the bottom center is another light gray rounded rectangle containing the text 'Adaptive Responses'. In the center of the diagram is a light gray circle containing the text '“fit”'. Dashed lines connect the right side of the 'Demanding Events' box to the left side of the 'Adaptive Responses' box, and both of these boxes are connected to the circle. Additionally, a dashed line extends from the right side of the circle towards the right edge of the slide.

**Demanding
Events**

“fit”

**Adaptive
Responses**

**Demanding
Events**

“fit”

**Adaptive
Responses**

**Complicating
Factors**

**Mismatches
Breakdowns**

**Demanding
Events**

**Adaptive
Responses**

**Complicating
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**Mismatches
Breakdowns**

**Demanding
Events**

Coping

**Adaptive
Responses**

**Extra
Adaptations**

**Complicating
Factors**

Mismatches

Breakdowns

**new
“fit”**

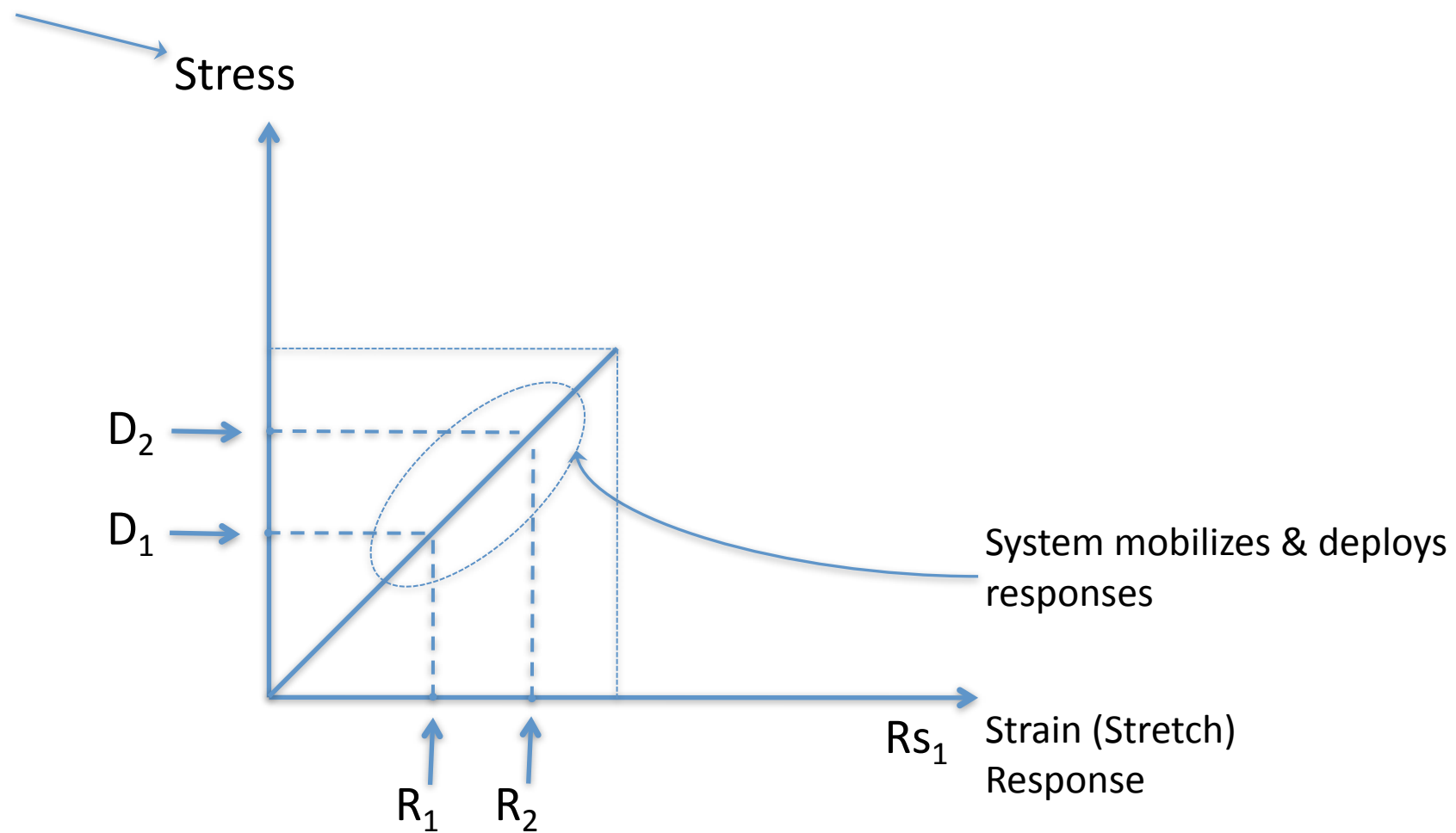
Coping

**Demanding
Events**

**Adaptive
Responses**

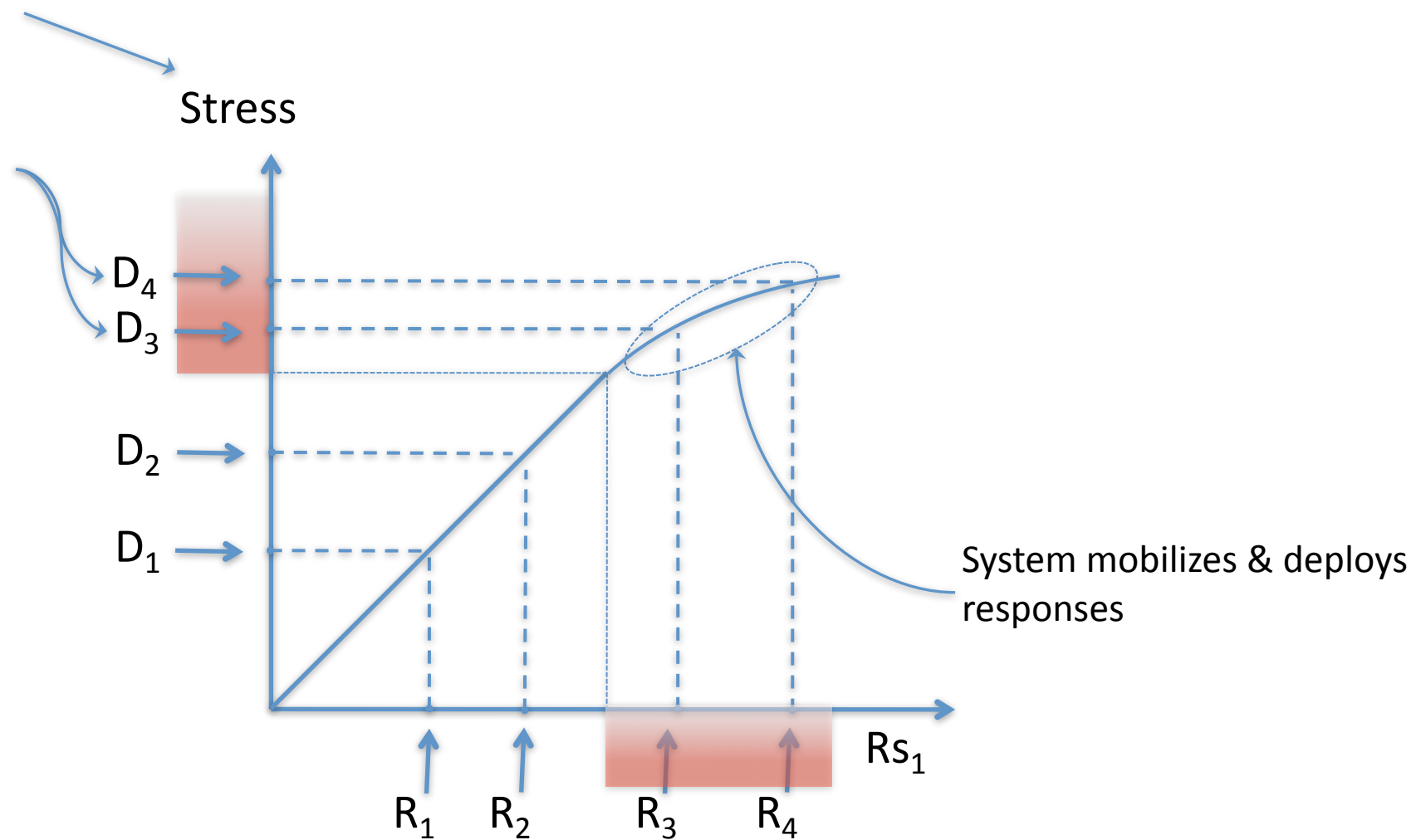
**Extra
Adaptations**

Variability changes
demands on system



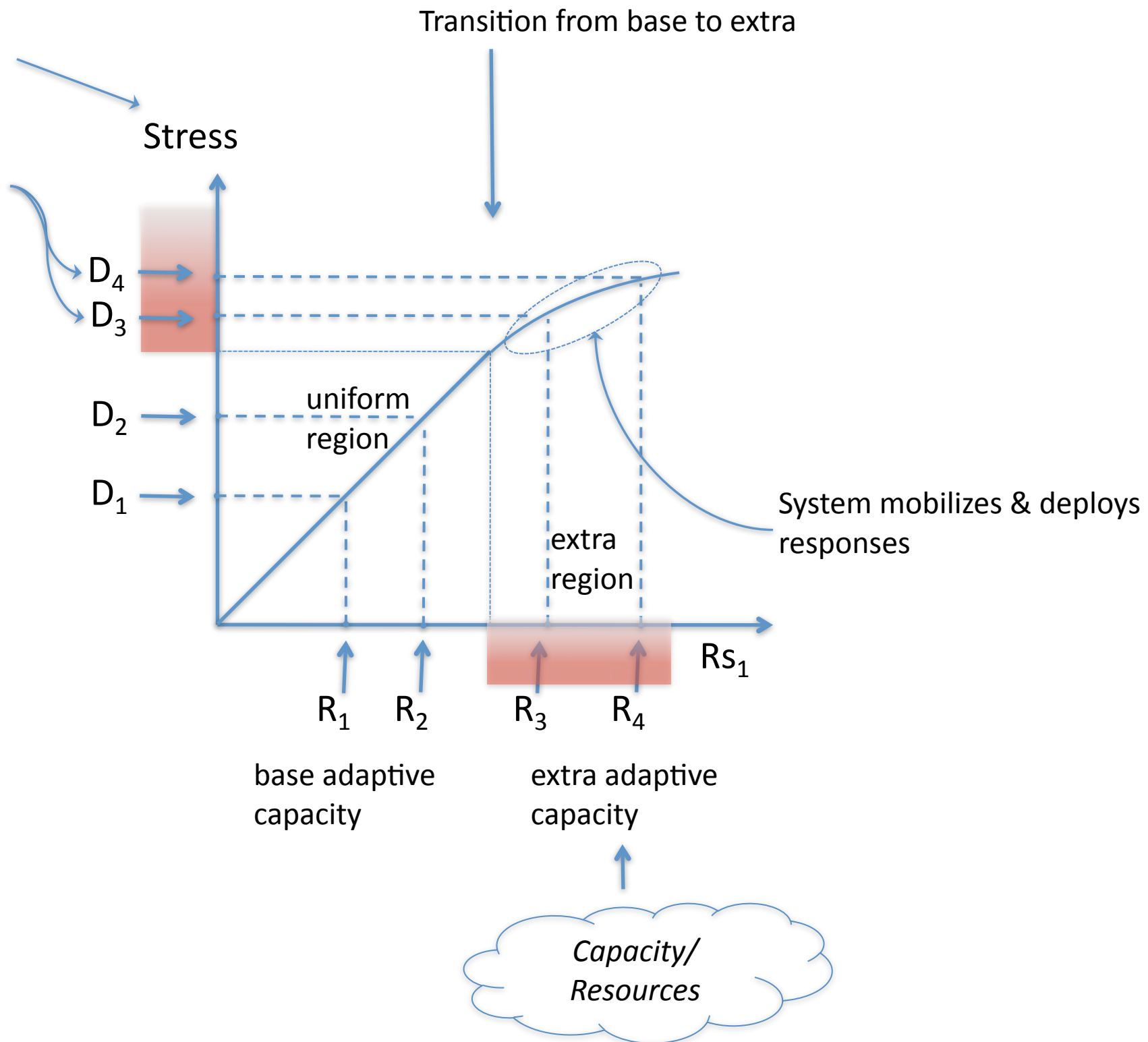
Variability changes demands on system

Challenge events

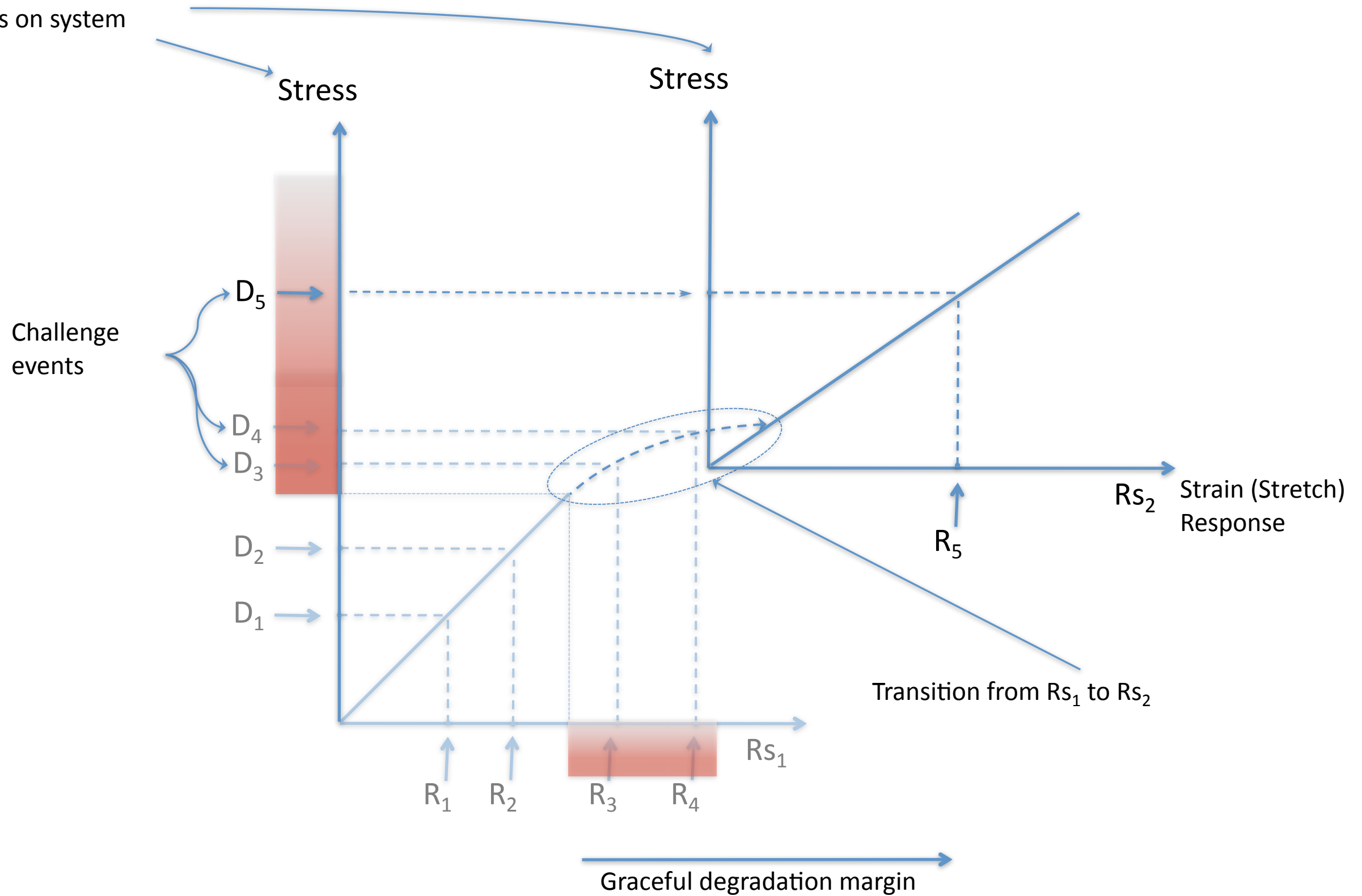


Variability changes demands on system

Challenge events



Variability changes demands on system

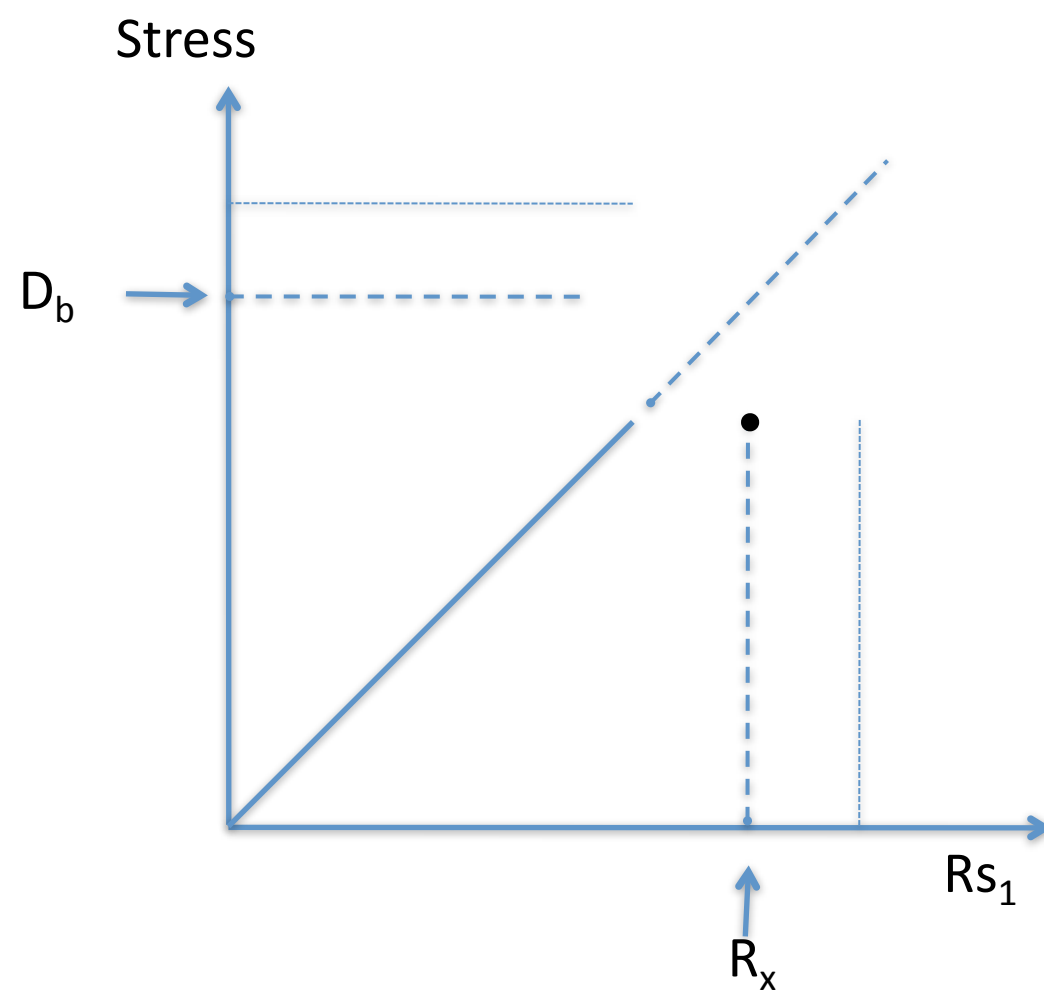


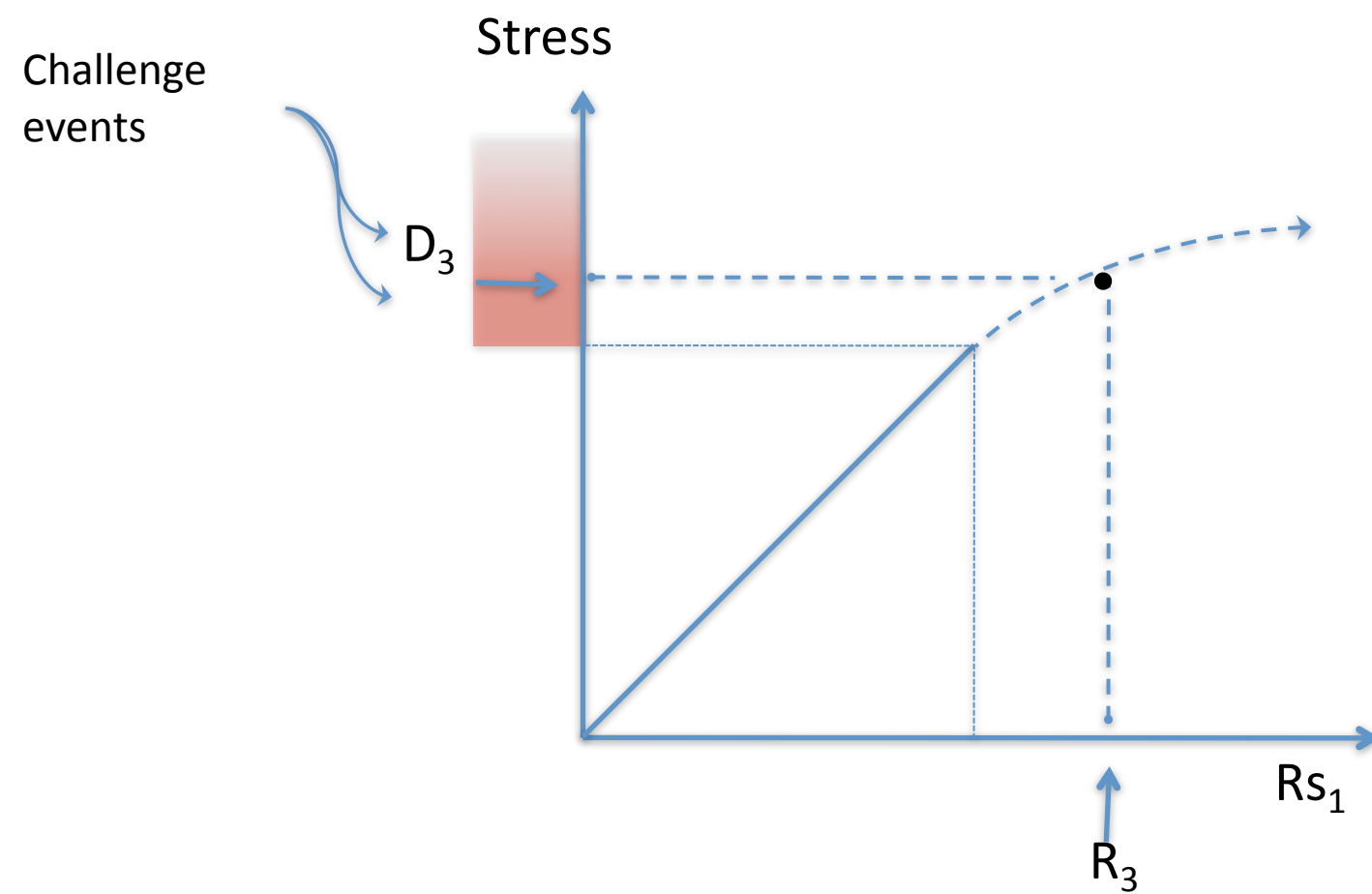
Tactical reserves how to develop, sustain, deploy

like cavalry charges in a battle -- they are strictly limited in number, they require fresh horses, and must only be made at decisive moments.

Alfred North Whitehead







Law of Fluency

“Well”-adapted cognitive work occurs with a facility that belies the difficulty of the demands resolved and the dilemmas balanced. Woods, 2002

A. Adaptive capacity exists before disrupting events call upon that capacity -- it is the potential for future adaptive action

B. One assesses (sees/models/measures) adaptive capacity through its exercise in the anticipation and reaction to past disruptions.

Resources that support the potential, prior to visible disrupting events, may not be seen at all since they are not used; or if seen, they will be seen as excess capacity since they are not in use.

Mis-Calibration

organization is operating more precariously than it realizes

Organizations generally

- ~ mis-estimate their adaptive capacity (level and kinds)
- ~ overconfident that they know it precisely

Resilient Organizations

- ~ acknowledge uncertainties and change
- ~ struggle to update and re-calibrate
- ~ support sacrifice judgments—contexts to relax acute goals to serve chronic goals

requires

- ~ perspective shifts/contrasts
- ~ managing appropriate skepticism
- ~ balancing the 4 I's across echelons:
independent, involved, informed and informative

- How to tell the difference between inefficiencies and sources for resilience?
- How to tell if system is getting more brittle?
- How will change expand or constrict adaptive capacities?
- Monitor and manage Margin of Maneuver (MoM)

4. Polycentric Governance and Control of Margin of Maneuver

David Woods

surprise is inevitable and ongoing:

how do plans survive or fail to survive contact with events?

goals interact and conflict:

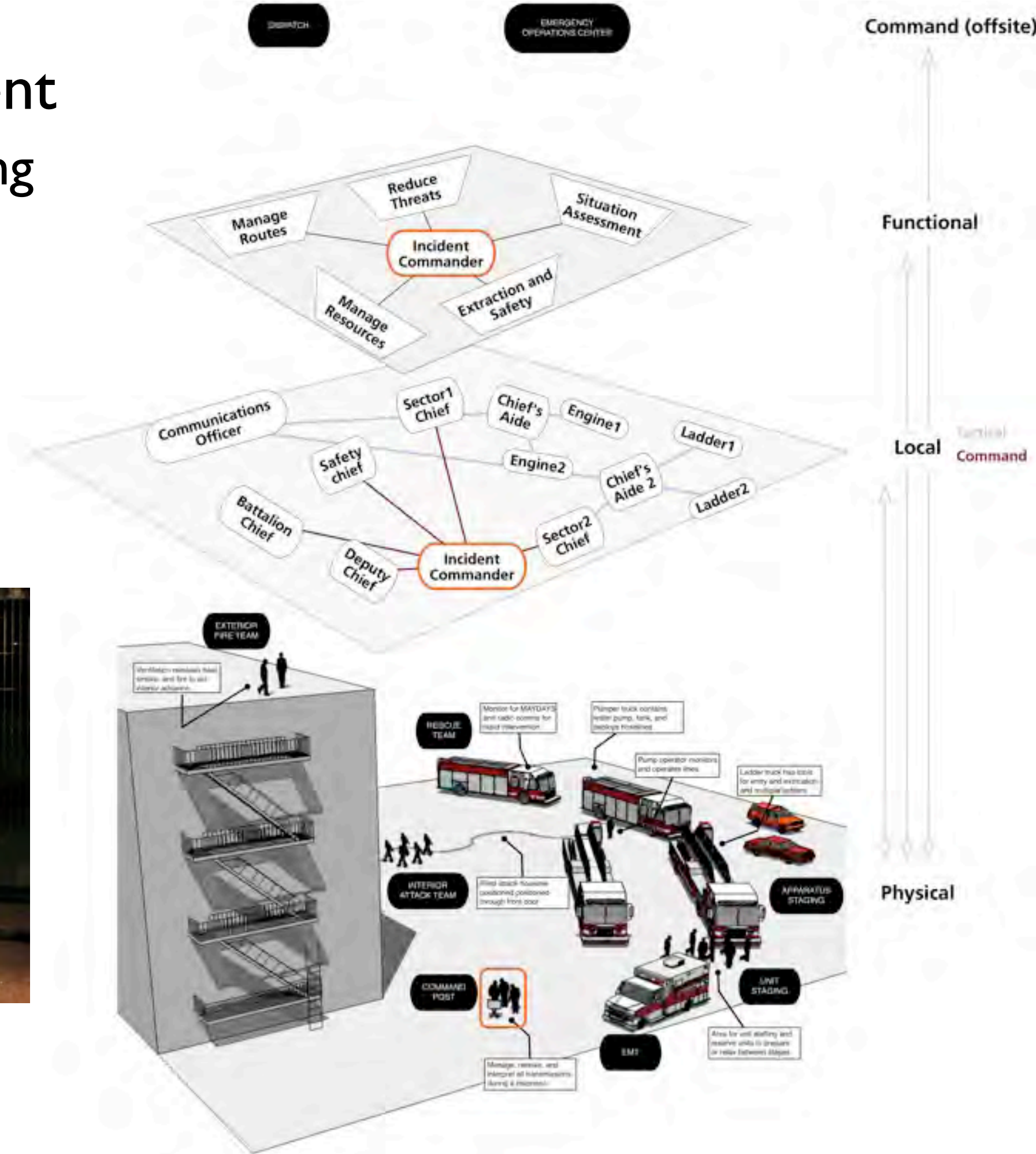
how do units meet their responsibility to achieve their goals?

- how does change squeeze margins?
- how do units respond to sustain or rebuild margin?
- how does one unit's response constrain other unit's ability to maneuver?
 - ~ horizontally across units?
 - ~ vertically across echelons?

Crisis Management

eg Urban Firefighting

- ~ distributed roles
- ~ multiple echelons
- ~ disrupting factors
- ~ multiple goals
- ~ interdependencies
- ~ all responsible in part



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Patterns of Adaptive Breakdown

Decompensation: exhausting capacity to adapt as disturbances/challenges cascade.

breakdown occurs when challenges grow and cascade faster than responses can be decided on and deployed to effect.

Working at cross-purposes: behavior that is locally adaptive, but globally maladaptive

inability to coordinate different groups at different echelons as goals conflict.

Getting stuck in outdated behaviors: the world changes but the system remains stuck in what were previously adaptive strategies.

Monitor/Regulate **Margin of Maneuver**:

Cushion of potential actions and additional resources that allows the system to continue functioning despite unexpected demands.

How much active control margin or capability is left to handle the next event or disturbance?

Each center of adaptive behavior works to create, maintain, and manage their margin of maneuver.

Locally adaptive as one center manages its margin relative to interdependencies with other centers' behaviors to manage their margin

Failure to maintain margin leaves the system too brittle and increases the risk of falling into the maladaptive traps (eg, locally adaptive, globally maladaptive)

Resilient systems are able to anticipate how margins of maneuver are expanding or contracting relative to the potential for surprise.

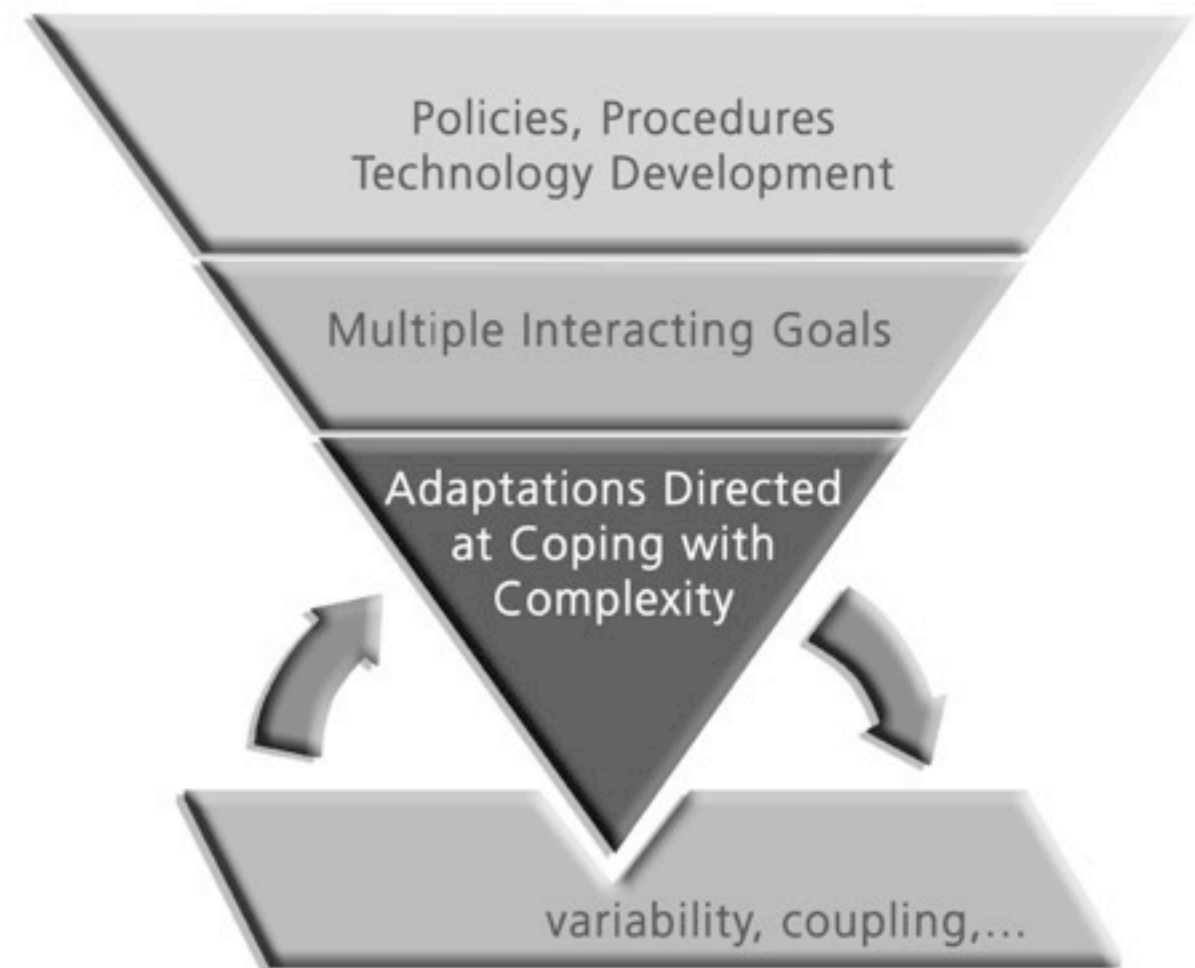
Co-adaptive cycles:

trace how change squeezes margins of maneuver

- ~ horizontally across units
- ~ vertically across echelons

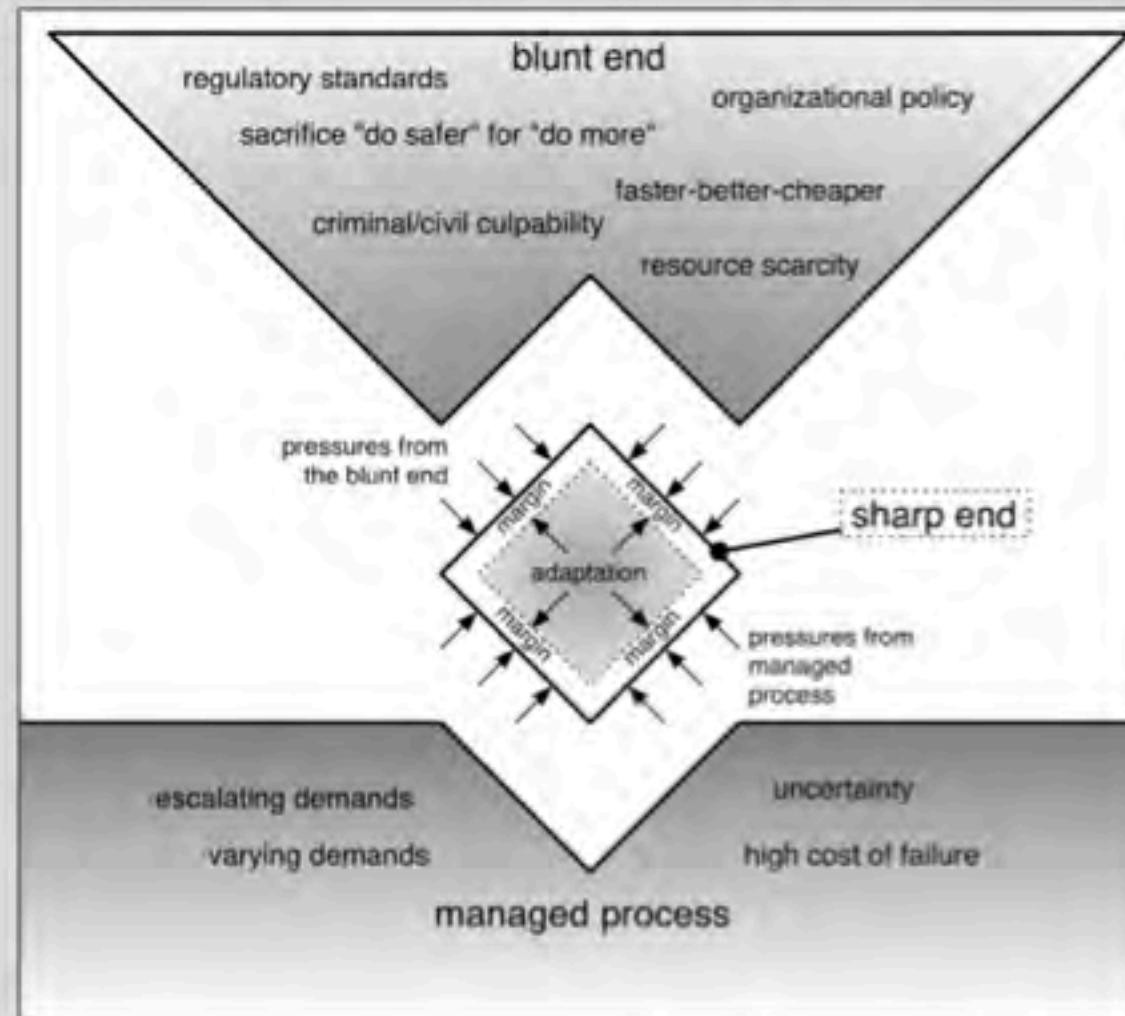
how CABs responses to sustain/rebuild margin of maneuver

- ~ horizontally across units
- ~ vertically across echelons



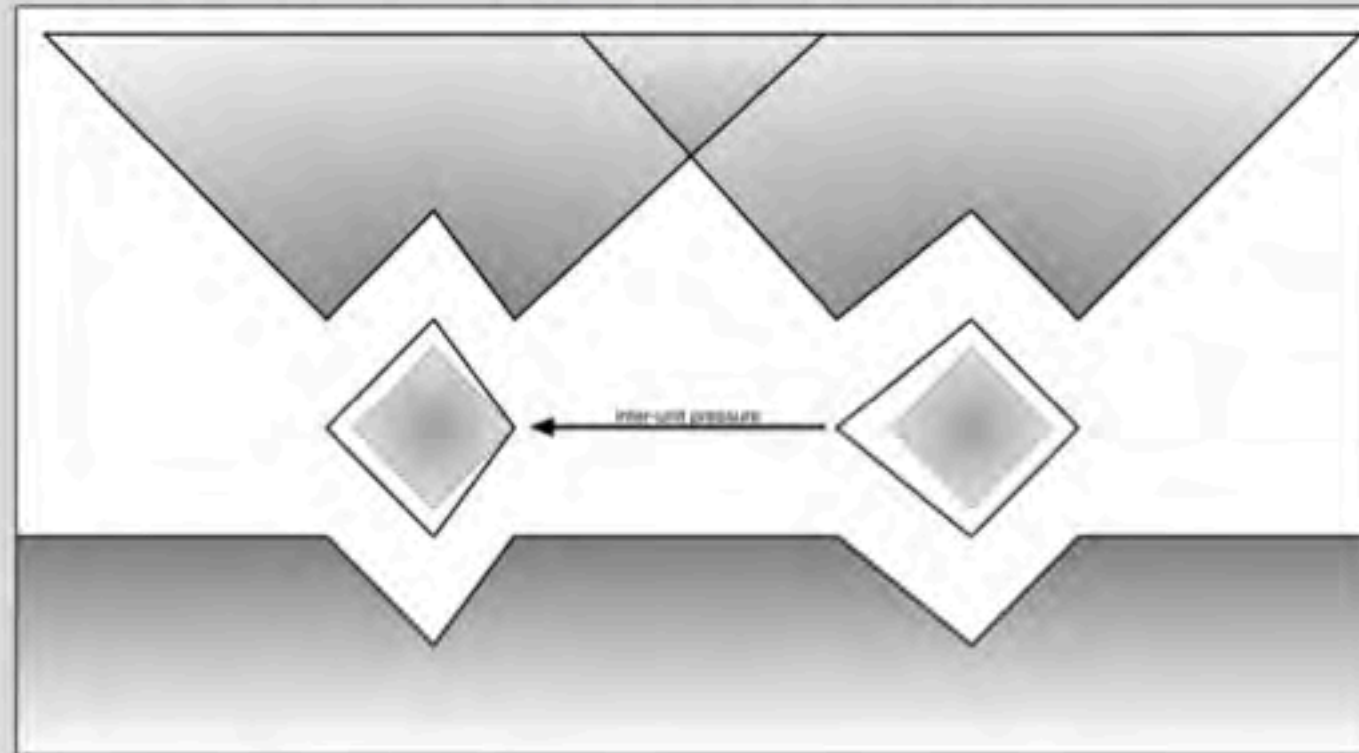
Resilient systems create and maintain **margins of manoeuvre**, cushions of potential actions or additional resources that allow the system to remain resilient despite unexpected demands.

Units within systems have varying, partial authority and autonomy to manage individual margins.



This framework classifies **locally adaptive strategies** to maintain margin into three categories by how they interact with other units' margins.

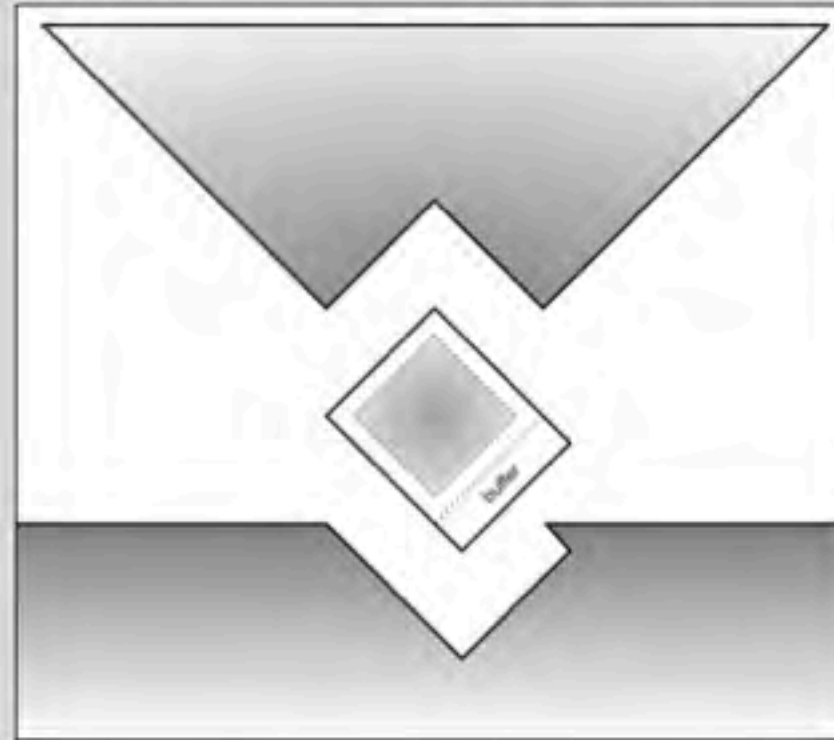
Defensive strategies maintain local margin at the expense of another unit by **restricting** other units' actions or **borrowing** other units' margins.



Observed Examples

- Inpatient units delay admission of patients from the emergency department to reduce their influx of patients, resulting in additional margin for inpatient units but placing a restriction on emergency department activities.
- Emergency departments use ambulance diversion to reduce the influx of patients, thereby borrowing margin from other local emergency departments and emergency medical services.

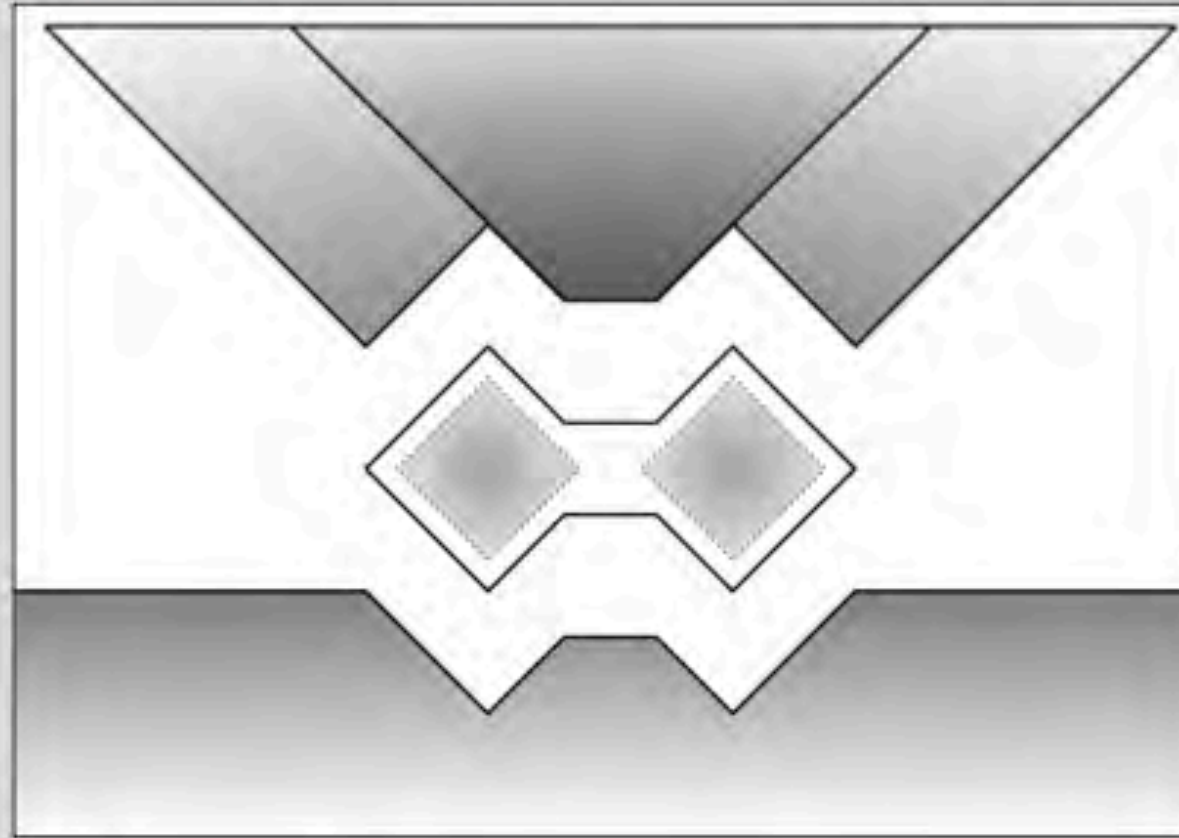
Autonomous strategies create margin through exclusively **local reorganization**, though possibly with indirect effects on the managed process or other units.



Observed Examples

- The emergency department anticipates *exception* patients that are difficult to admit by creating a specialized buffer. This strategy reduces the resources required to hold these patients, freeing up additional margin elsewhere in the unit.
- The emergency department pre-plans for sudden increases in load by placing some patients in chairs (rather than beds), creating a visual indicator of which patients are healthy enough to wait.

Cooperative strategies jointly recognize and manage existing **common pool resources**, or create new common pool resources that allow sharing of margin.



Observed Example

- Anticipating instances where demands may degrade one unit's capacity but not the other, an inpatient unit and the emergency department mutually agreed to surrender local resources to create a common pool sub-unit to care for boarded patients.

Managing Margin of Maneuver

Planned for MoM (built into base)

Nominal

- ~ work to plan/rule/role assumes sufficient adaptive capacity built into planful behavior;
- ~ assumes variability and surprise from outside the boundaries can be eliminated/defended
- ~ MoM mis-seen as inefficiencies to be eliminated
- ~ poorly calibrated and overconfident

Ad hoc

- ~ inevitable limits and surprises
- ~ responsible roles develop and sustain MoM --> covert work systems

Managing Margin of Maneuver

Performance oriented systems

- ~ regularly confront surprise and adapt to handle surprise events;
- ~ able to anticipate and recognize changes in potential for surprise and fluently transition to bring extra adaptive capacity to bear
- Deploy MoM
- Mobilize resources for MoM
- Learn - reflect about MoM
- Generative MoM [ability to create new MoM] (evolvability in biology)
 - ability to generate new margin in new ways (phenotypically) in response to future events (not foreseeable today)
 - conserved genotypical mechanisms that generate adaptive capacity for future contexts “constraints that deconstrain”
 - organizations are able to learn effective responses to new challenges rapidly (Israeli medical response to bus bombings)

Polycentric Governance

- multiple centers of adaptive behavior (CABs) under the 5 bounds
- interdependent,
- each with partial authority and
- partial autonomy,
- partial responsibility, to meet the goals of their scope relative to overarching goals

performance emerges from how the different centers regulate and coordinate their activities relative to other centers and changing demands

Polycentric Governance

History / Proof of Concept:

- ~ Tragedy of the commons: Ostrom 1999 - Nobel 2009
- ~ military doctrine: commander's intent, Von Clausewitz
- ~ mission control anomaly response: Watts-Perotti/Woods 2009

Critical Properties:

- Reciprocity (Ostrom)
- Basic Compact (Klein et al.)
- Accountability Systems (Tetlock)
instabilities eg role retreat, risk shifting
- Shift Forms of Coordination over Centers (Nyssen, Smith)
- Ability to Anticipate Bottlenecks Ahead
- How Initiative is Delegated and Regulated
- Monitor how hard other interdependent centers are working to maintain control (CSCW)

Polycentric Governance

Network of interdependent adaptive units operating over different scopes.

Strategy for:

- empower decentralized initiative
(at Sharp End Layer, up close roles)
- coordinate over emerging trends to meet priorities
(Broad End Layer, distant 'supervisory' roles)
- dynamic interplay as situations evolve in themselves and as a result of activities at different centers across levels

Test Cases for Polycentric Control

- cyber security,
- emergency informatics,
- resilient infrastructures,
- cyber-physical systems,
- netcentric operations,
- layered sensing systems

...,

multi-echelon, distributed, networked systems where interdependent activities play out over wider ranges and scales